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WAVE CLIMATE DOCUMENTATION STUDY

PREPARED FOR

TRANSPORT CANADA

TRANSPORTATION DEVELOPMENT CENTRE

MONTREAL

BY

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OTTAWA

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

The report describes available wave and wind data that are representative of Canadian waters and other defined areas. An extensive bibliography of reports referring to these data is included. These data include instrument recordings, ship observations and the results of wind-wave hindcasts.

The details of the major wind-wave hindcasts undertaken to provide data for the north-west Atlantic and the Canadian Arctic waters are summarized.

Recommendations are made concerning the future directions of the studies required for the implementation of ship strength standards and regulations that involve the definition of the wave climate and ship response to waves.

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17. Résumé

La rapport décrit les données sur les vents et la houle disponibles présentement pour les eaux canadiennes et d'autres régions bien définies. Une bibliographie exhaustive de rapports traitant de ces données est incluse. Ces données comprennent des résultats d'enregistrements par des instruments, des observations par des navires et des prévisions a posteriori des vents et de la houle.

Les détails de prévisions a posteriori les plus importantes, entreprises pour obtenir des données sur le nord-ouest de l'Atlantique et dans les eaux arctique canadiennes, sont résumés dans le rapport.

Des recommandations sont formulées pour diriger les études futures nécessaires à l'elaboration de normes et de réglements pour la résistance structurale des navires, impliquant la définition et de la réaction des navires aux dites vagues.

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FOREWORD

Transport Canada is responsible for the development and implementation of strength standards and regulations for Canadian ships and floating structures. To fulfill this responsibility as new ships and structures are built and new routes are established, Transport Canada is improving its capability to define structural strength standards and regulations for ships and floating structures that are commensurate with the marine environment in which the vessel or structure will operate.

This study, which is an initial step in the development of the methodology for determining the strength of a ship or structure in a defined environment, documents available data that describe the wave and wind climate of Canadian and adjacent waters. It describes the availability of wind-wave hindcasting procedures and documents archived hindcast data. The report recommends formats for presenting wave and wind data that are suitable for future analyses of the response of ships and floating structures to waves and wind.

SUMMARY

This report provides a definitive description of available data describing the wave and wind climate of Canadian waters and other defined areas. These data include instrument recordings, ship observations and the results of wind-wave hindcasts. An extensive bibliography of technical reports describing these data is included.

Wind-wave hindcast procedures are discussed and details of the major hindcasts undertaken to provide data for the north-west Atlantic and the arctic are provided.

Procedures for calculating ship response to wave action are reviewed and the wave data requirements of the analysis procedures are summarized.

Recommendations are made concerning the future direction of studies required for the implementation of ship strength standards and regulations. It is recommended that a Canadian capability to hindcast waves be developed in co-operation with other government departments. It is also recommended that future standards and regulations concerning the strength of ships and floating structures be based on calculation of the stresses in a ship or floating structure produced by wave loadings.

Table of Contents

1 INTRODUCTION.....1

2 DEFINITION OF AREAS CONSIDERED.....3

3 WAVE DATA.....4
3.1 General.....4
3.2 Instrument Measurements.....6
3.3 Ship Observations.....8
3.4 Wave Hindcasts.....9
3.5 Remote Sensing.....11

4 WIND DATA.....15
4.1 General.....15
4.2 Instrument Measurements.....15
4.3 Ship Observations.....16
4.4 Wind Data Derived From Pressure Field Data.....17

5 WAVE PREDICTION METHODS.....19
5.1 General Discussion.....19
5.2 U.S. Navy Fleet Numerical Weather Central - Spectral Ocean Wave.....20
5.3 U.S. Army Engineers Waterways Experiment Station-Resio Model.....22
5.4 Beaufort Sea Hindcast Model.....22

6 SHIP RESPONSE ANALYSIS AND WAVE DATA REQUIREMENTS.....24

7 SUMMARY AND DISCUSSION.....28
7.1 Wave Data.....28
7.1.1 Ship Stress Calculations and Requirements for Wave Data.....29

8 CONCLUSIONS AND RECOMMENDATIONS.....31

APPENDIX A-1 Summary of NEDS Historical Wave Measuring Stations...38

A-2 Summary of Selected National Buoy Office Wave Recording Stations 45

A-3 PIANC Glossary of Terms 49

A-4 List of Organizations Producing or Archiving Wave Data 53

APPENDIX B Bibliographies

Bibliography 1 - Wind and Wave Data
Bibliography 2 - Wind and Wave Forecasting (Hindcasting) Procedures
Bibliography 3 - Wave Induced Ship Stresses and Ship Response

1 INTRODUCTION

Transport Canada is responsible for implementing regulations concerning strength standards for ships and other floating structures. In order to meet this responsibility, procedures for relating the wave and wind climate of a defined area to strength requirements of ships travelling through the area, or a floating structure moored in this area, are continuously being developed and assessed.

In the past, approval of a specific route was largely based on the concept of a "successful ship" in a base service. A "successful ship" was a class of ship which experience had shown could withstand the environment of a given area without major structural problems. Approval of a new route for an existing ship was based on a comparison of the wave climate of the new area with the existing area of operation or base service.

This approach is not valid for new ships or floating structures for which a base service has not been established. Consequently, in recent years, the capability of calculating a ship's response to quasi-static and transient wave loads has been developed. Considerable success has been achieved in defining absolute values of stress and these new procedures are now being increasingly used in the design, classification and regulation of ships and are exclusively used for the design of floating structures. It can be expected that, in future, ship strength standards will be based on the calculation of the absolute value of stress resulting from the static and dynamic loadings that can be expected in a defined sea state, and not on relative comparisons of wave climates or ship strengths.

This study is a small part of a long term plan to develop a Canadian based technology to assist Transport Canada in assessing structural requirements for ships in any given wave and wind climate. The results of this assessment will play a major role in the designation and approval of shipping routes.

The development of the required technology will involve the following activities:

- the development of a capability of providing a detailed description of the wave climate of any area under study

- the use of numerical procedures for calculating a specific ship's response to a defined wave and wind environment

- the development of a capability of assessing the results of the ship response calculations and implementing applicable regulations for ship safety

Site specific studies of waves and ship response have been completed under contract in the past to assist Transport Canada with the

implementation of strength standards and the approval of routes. A recent study of the Transportation Development Centre addressed the different wave climates of the Gulf of St. Lawrence and Lake Superior and recommended variable increases in the strength requirement of lakers using the Gulf of St. Lawrence as a function of the anticipated operating season in the Gulf (1). The study was based on the concept of a "successful ship" in a base service.

This study has the objective of documenting available information describing the wave and wind climate of Canadian and other specified areas. These data will be required for the implementation of a general methodology for relating the marine environment of a given area to strength standards for ships making passage through that area and for floating structures required for the exploration and recovery of oil and gas.

The application of wind-wave hindcasting procedures in defining a continuous, long-term wave climate and the presentation of wave and wind data in a suitable format for ship response calculations are discussed.

Throughout this study, particular emphasis is given to the arctic regions of Canada and to an area off the east coast of Canada and the United States, extending to Kingston, Jamaica (Figure 2.1). This latter area is of concern because a bulk carrier is currently being built for trade to the Caribbean.

2 DEFINITION OF AREAS CONSIDERED

In the literature and data searches completed during the course of this study, all Canadian waters have been considered, as well as the north-west Atlantic and the north-east Pacific. Particular attention has been given to locating wave and wind data for arctic regions and an area east of Canada and the United States extending to Kingston, Jamaica, as shown in Figure 2-1.

In the wave and wind data bibliography included in this report, the references are listed by the following areas:

A. Atlantic Ocean, including the Gulf of St. Lawrence, Canadian Atlantic and the U.S. Atlantic coastlines

B. North Atlantic (north of 52 degrees latitude) and Davis Strait

C. Canadian Arctic

D. Great Lakes

E. Northeast Pacific Ocean (north of 48 degrees latitude)

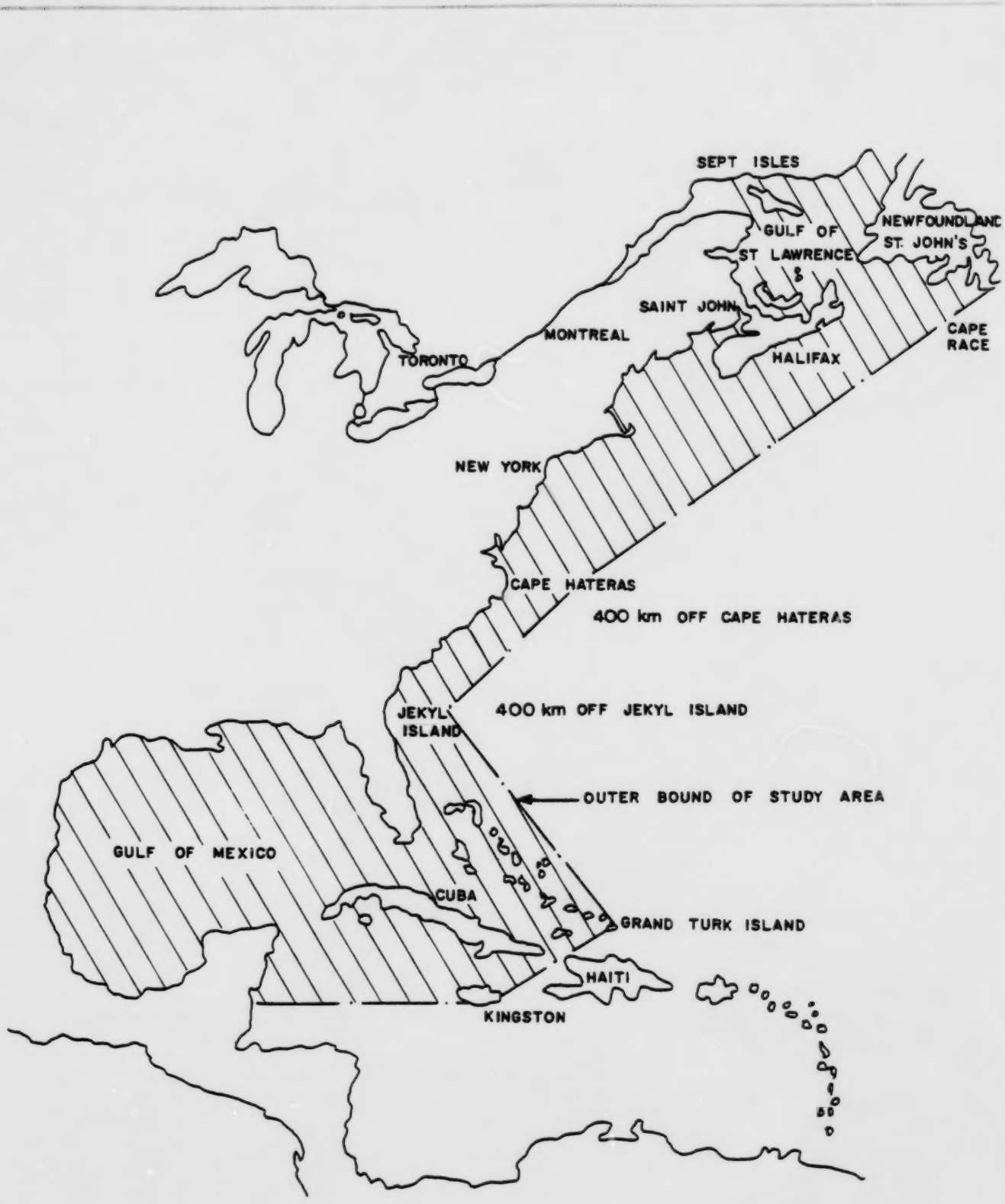


FIGURE 2.1 OFFSHORE BOUNDARY OF PROPOSED SHIPPING ROUTE TO THE WEST INDIES (DEFINED BY TRANSPORT CANADA)

3 WAVE DATA

3.1 General

Wave data fall into the following categories:

- measurements by instruments deployed in the ocean

- observations by ships' officers (ship observations)

- predictions of wave conditions produced by numerical models of wave generation by wind (wave hindcasts or forecasts)

- estimates of wave conditions obtained by combining measurements, ship observations, and predictions to provide synoptic summaries of wave conditions over an area

- measurements by remote sensing devices, such as radar or laser systems. The sensor may be installed on land, in an aircraft or in a satellite.

The major sets of wave data that have been archived are summarized and discussed in the following sections of this report. All references for the wave data are contained in the bibliography by geographical area, as defined in Section 2.0.

The usefulness of a particular set of archived wave data to future studies of ship response, depends on the following characteristics of the data:

- Whether or not the data represent a relatively large area of water or are site specific. In general data recorded in shallow water or close to a shoreline will only be representative of the instrument's location and they will have limited application to any adjacent area. Wave measurements obtained using wave recorder buoys at coastal locations will, therefore, have very limited application to future studies of ship response.

- The accuracy and reliability of the data. Ship observations of waves are generally considered to be relatively unreliable because of individual observer and fair-weather biases.

- The completeness of the available description of the wave conditions. Ideally, for the purpose of calculating ship response, directional wave spectra and water surface profiles recorded in severe storms are required. None of the available data are fully satisfactory.

- The length of time covered by the data. Long term coverage of any area is required to provide a reliable estimate of the wave climate of any one area. At the present time, all data except for ship observations and some wave hindcast results, provide only limited coverage.

- Constant coverage (constant in format and accuracy) in all areas of interest. The only data that come close to meeting this requirement at this time, are ship observations. However, even these data provide limited coverage in the arctic regions of Canada. In the future, wave hindcasts could provide consistent results over many regions.

The glossary of terms for describing waves prepared by PIANC is included in Appendix A. These terms are used throughout this report.

3.2 Instrument Measurements

Wave measurements have been obtained at many sites for intermittent periods of time. A wide variety of instrumentation and data collection systems have been utilized to obtain the wave data including accelerometer buoys, staff gauges, ship-borne instrumentation (including radar profilometers, Tuckermeters and numerous case-designed wave recorders) and, more recently, satellite imagery. However, the relatively short period of coverage and the discontinuity of the measured wave data, both spatially and in time, does not allow a reliable estimate of the wave climate, particularly extreme events or design wave conditions that are required for assessing strength requirements for ships operating in the area.

Most of the measured wave data considered in this study have been analyzed and archived by the National Oceanic and Atmospheric Administration and the National Oceanographic Data Centre in the United States, and the Marine Environmental Data Service, Department of Fisheries and Oceans, Canada. The following list provides a brief description of these organizations, including the location, coverage and reliability of the wave data that are archived and in addition, provides a brief description of wave data measured and reported by other sources:

(1) Marine Environmental Data Service (Department of Fisheries and Oceans), Ottawa, Canada.

The MEDS has been largely responsible for retrieval, analysis and presentation of data from the majority of wave measurement programs undertaken in Canadian waters in the past 12 years. Waves have been measured at approximately 200 locations using waverider accelerometer buoys and wave staffs. In recent years, extensive data have been collected in the Beaufort Sea and off the East Coast of Canada by a number of companies involved in oil and gas exploration in co-operation with MEDS.

A station location summary of the MEDS historical wave measuring stations is available from MEDS (2) and is presented in Appendix A-1. The summary includes the geographic location of the station, the period of the recording, and the success of the measurement program. Figure 3.1 shows the locations of the measurement stations. In addition, the MEDS also provides individual station summaries which include frequency of occurrence tables of wave height and wave period, exceedance diagrams and monthly plots of the wave conditions. Available on request are: the wave spectrum and surface trace for each 20 minute wave record obtained generally at three-hour intervals.

Relatively long-term coverage has been obtained with the recorders installed at Weather Station Papa, in the North Pacific (1975-1979); Tofino, B.C. (1970-1982); Torbay, Newfoundland (1972-1982); and Osborne Head, N.S. (1971-1982).

NOTES 1 PERIODS OF RECORDING FOR EACH LOCATION ARE LISTED IN APPENDIX A

2 - THE STATION LOCATION REPORTED ON THIS FIGURE IS REPRESENTATIVE OF THE AVERAGE LOCATION OF THE STATION OVER VARIOUS RECORDING PERIODS (SOME STATION LOCATIONS HAVE VARIED SIGNIFICANTLY AN ARE THEREFORE REPORTED INDIVIDUALLY)

THE INFORMATION IN THIS FIGURE IS BASED ON DATA OBTAINED BY MEDS PRIOR TO JUNE 1982

FIGURE 3.1 LOCATION OF MARINE ENVIRONMENTAL DATA SERVICE HISTORICAL WAVE RECORDING STATIONS

(2) National Data Buoy Office (NDBO)

A station location summary of the data recording stations at which NDBO environmental buoys were deployed is presented in Appendix A-2. Wave data measured at these buoy locations is archived on magnetic tape at the National Oceanographic Data Centre, Environment Data Information Service. Figure 3.2 shows the location of NDBO recording stations along the eastern seaboard of the United States.

(3) National Oceanographic Data Centre, Environmental Data Information Service (EDIS), Washington, D.C.

The NODC has archived most recorded and hindcast wave data recorded by U.S. sources including NDBO data buoy measurements, results of the U.S. Navy SOWM hindcast and wave measurements made by private companies, in particular, companies involved with oil and gas exploration.

(4) The U.S. East Coast Rig Instrumentation Program (ECRIP)

The program was set up and sponsored by a number of oil companies involved in oil and gas exploration and production off the east coast of United States. The program was implemented to achieve these objectives:

(i) to collect data to be used to determine design and operational criteria for offshore facilities and pipelines,

(ii) to provide calibration and verification data for real-time wave forecasting and,

(iii) to provide data to meet the demands of regulatory bodies.

A discussion of ECRIP is found in Rose et al (3). A wave measurement program is currently being undertaken in the Baltimore Canyon area located approximately 100-150 miles off the coast of New Jersey (approximately 39 degrees north latitude, 73 degrees west longitude). Results of the first season of measurements (April 1978 to February 1979) are presented in Forristall (4). Data presentations include monthly, season and directional statistics of wind speed, significant wave height and wave energy spectra.

(5) U.S. Coast Guard, Ship Structure Committee

A program was undertaken by the Ship Structure Committee (SSC) to provide direct instrumental measurement of the wave environment and associated ship stresses so that existing numerical ship stress prediction programs could be verified and calibrated using

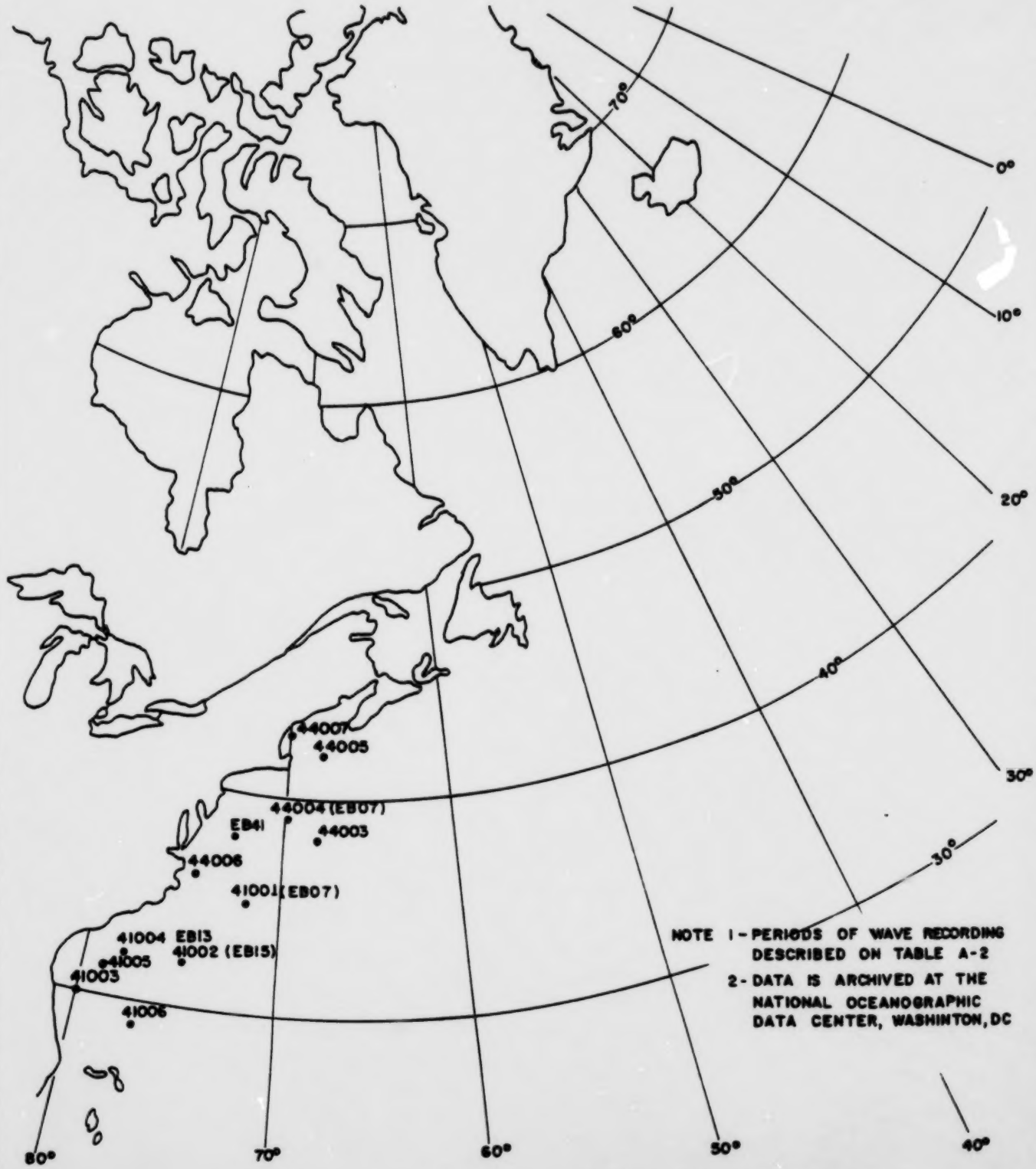


FIGURE 3.2 LOCATION OF NATIONAL DATA BUOY OFFICE HISTORICAL WAVE RECORDING LOCATIONS NW ATLANTIC

full scale service data. The containership, the S.S. Sea-Land McLean, was outfitted with two wavemeters, a microwave radar wavemeter with a resolution of 21cm and a "Tucker-Meter" pressure actuated wave measurement system with a resolution of 6cm.

Significant height and significant wave period was measured at four-hour intervals during Trans-Atlantic voyages undertaken during three winters (1972-1973, 1973-1974 and 1974-1975). The data are presented in a series of reports published by the Ship Structure Committee (SL-7-1 through SL-7-23) and are listed in bibliography 1-F.

(6) Wave Climate Study - Great Lakes and Gulf of St. Lawrence
National Research Council, Hydraulic Engineering Lab, Ottawa

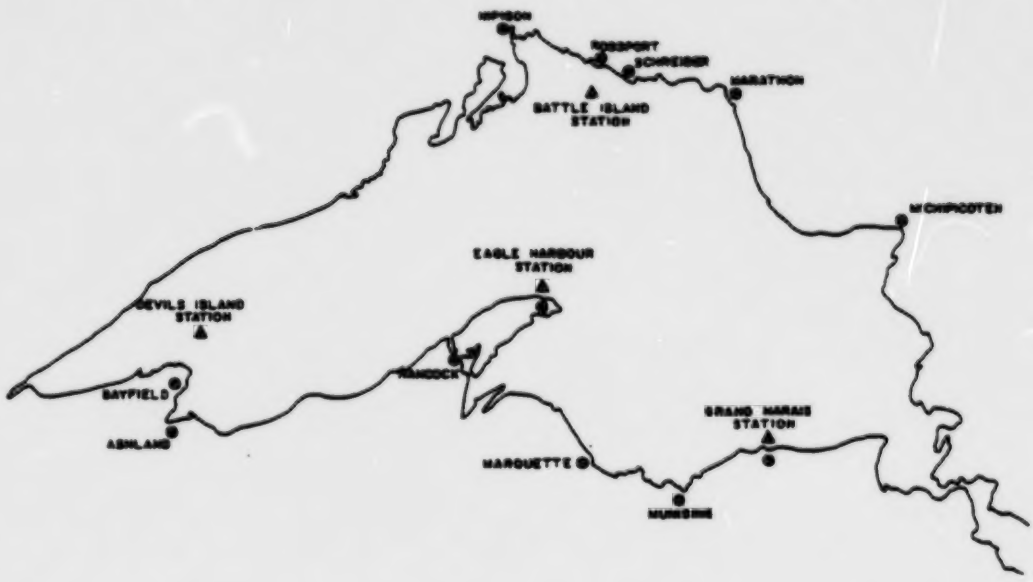
A wave climate study of the Great Lakes and Gulf of St. Lawrence was undertaken over a period of three years (1965-1967). Waves were recorded at 14 locations in these areas (Figure 3.2), using an accelerometer wave buoy. The results are presented in Ashe and Ploeg (5), and include a description of the wave climate using the significant wave height and the peak wave period of the energy spectrum as the descriptive sea-state parameters.

3.3 Ship Observations

The majority of visual ship observations which have been archived since the early 1900's are concentrated along the major shipping lanes. The accuracy and reliability of the ship observations are often questioned because the effects of the individual observer bias and the tendency of ships to avoid severe storms. The significant wave height, significant wave period and direction of the locally generated sea and of the swell, are reported. The significant wave height in this case, is defined to be "the average height of the large, well-formed waves."

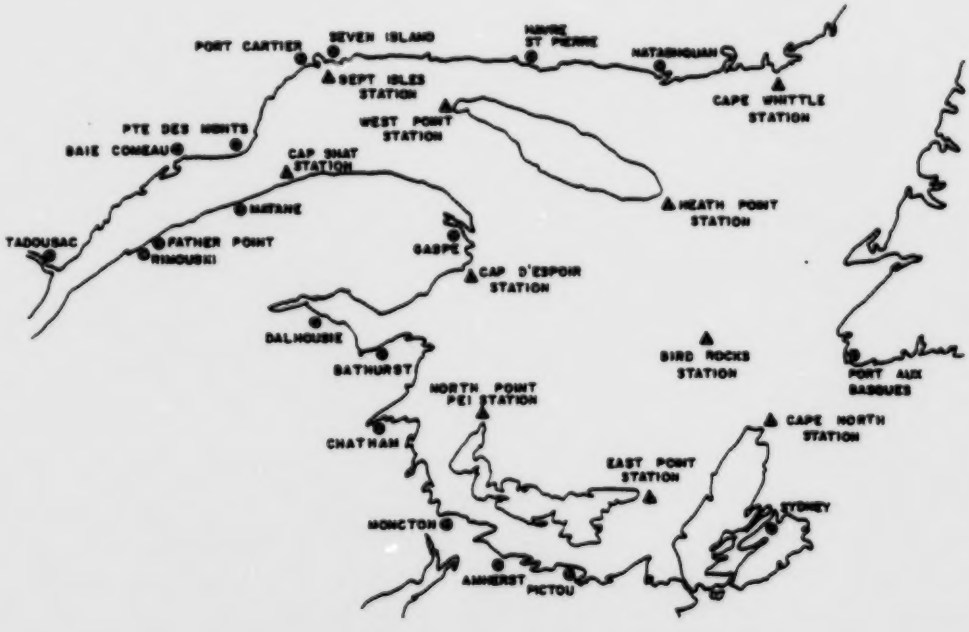
The Synoptic Shipboard Meteorological Observations, (SSMO), prepared by the U.S. Naval Weather Service Detachment, are derived from surface marine observations from ship logs, ship weather reports, published ship observations, automatic observing buoys and data from foreign marine services. The quality of the data varies considerably because of the variation in the quality of instrumentation and the qualifications of the observers. Charts are prepared for various areas around the world. The main grid, which consists of squares, 10 degrees longtitude by 10 degrees latitude, is subdivided into 100 subsquares, each square covering an area of 1 degree longitude by 1 degree latitude. Wave data are summarized for each subsquare. S.S.M.O. data for each subsquare are archived at the National Oceanic and Atmospheric Administration, Ashville, North Carolina.

A series of isolines of significant wave height, on a chart of the northwest Atlantic, are produced twice daily by the Canadian Forces



LAKE SUPERIOR WAVE RECORDING STATIONS

▲ ACCELEROMETER BUOY LOCATION



GULF OF ST LAWRENCE WAVE RECORDING STATIONS

FIGURE 3.3 WAVE RECORDING LOCATIONS - GREAT LAKES AND GULF OF ST. LAWRENCE WAVE CLIMATE STUDY (AFTER ASHE AND PLOEG, 1971)

METOC Centre, Halifax, and are archived on magnetic tape by the Atmospheric Environment Service, Department of the Environment, Canada. The charts cover the North Atlantic Ocean between 25 degrees north longitude and 70 degrees north longitude, excluding major embayments including the Gulf of Mexico, Gulf of St. Lawrence and Hudson Bay. The program has been in operation since 1970.

The main grid used in the preparation of the charts, consists of squares of five degrees latitude by five degrees longitude, except in coastal areas where the grid has been distorted to accomodate the coastal topography.

The main data base used in the preparation of the METOC charts is ship observations supplemented with real-time wave rider buoy measurements from exploratory oil rigs and coastal locations, and hindcast wave data developed using weather forecasts and primitive hindcasting techniques. The data are digitized to the central point of each square. The value of wave height recorded for each grid square is the highest value of significant wave height that was observed or predicted to occur within the square at the time of mapping. Isolines of significant wave height are then extrapolated onto the grid. The estimated accuracy of the isolines is 0.1 metre. The associated wave period and direction are values representative of the wave height in each grid square and are deduced from the surrounding data by the analyst preparing the chart.

The wave predictions used in the preparation of the METOC charts take into acount ice conditions limiting wave generation and propagation. It is assumed that a mean ice concentration of 3/8 to 6/8 (open pack ice) determined from mid-month ice conditions (based on all available observations) will limit wave conditions.

The METOC procedure is also utilized in a wave forecast mode providing 12, 24 and 36 hour prognostics.

The reliability of the archived METOC data is considered good, since the data must go through rigorous screening procedures in order to produce the wave height isolines.

An estimate of sea-state conditions for various areas around the world based on a large number of ship observations recorded between 1953 and 1961 is presented in Hogben and Lumb (6). The sea state is defined in terms of significant wave height and significant wave period for 12 compass directions. However, the majority of observations were made on British trade routes resulting in a geographical bias due to an unweighted accumulation of wave statistics over several areas as described by Bales (7). Ship observations are also summarized in a number of other oceanographic publications.

3.4 Wave Hindcasts

At present, several numerical wind-wave hindcast programs exist which have produced quantities of wave data representative of periods of more than 10 years. Specific details of these hindcasts is presented in

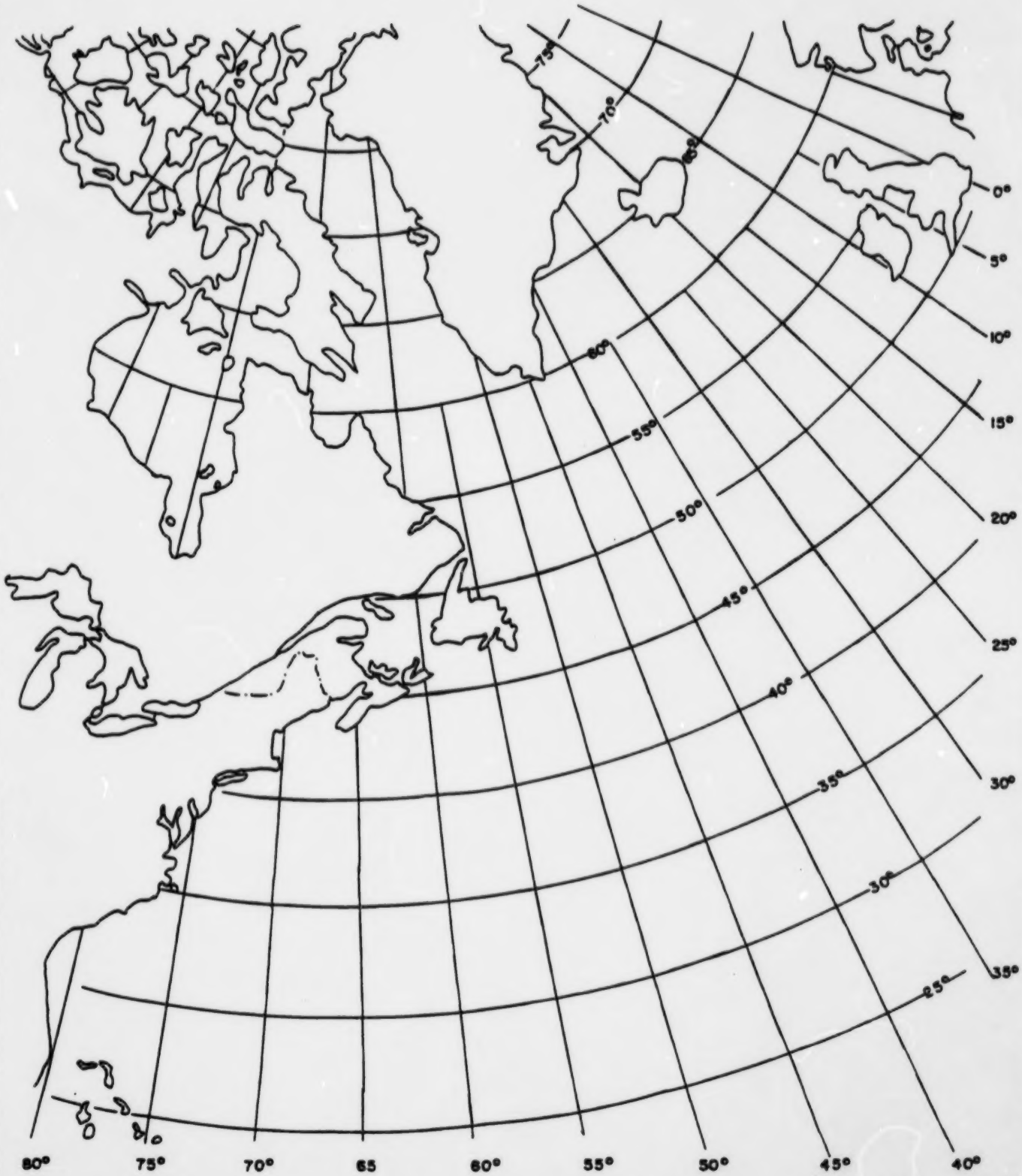


FIGURE 3.4 METOC GRID (CANADIAN FORCES METOC CENTER, HALIFAX)

Chapter 5. This section of the report will deal only with summarizing the wave data produced by these hindcasts.

(i) U.S. Navy Fleet Numerical Weather Central-Spectral Ocean Wave Model (SOWM)

The SOWM hindcast procedure is used by the U.S. Navy to produce predictions of sea state throughout the world for military purposes. The model hindcasts directional wave spectra using historical pressure data to derive the windfields (Lazanoff and Stevens, (8)). The directional spectra are hindcast every 6 hours (03Z, 09Z, 15Z and 21Z hrs.) and are defined by a distribution over 15 frequencies and 12 directions. A recent application of the SOWM model was to hindcast and archive 20 years of wave data at 3400 grid points in the northern hemisphere. Grid spacing along the eastern seaboard of the United States and off the east coast of Canada is approximately 381km and is shown in Figure 3.5.

The 20-year wave spectral climatology produced by the SOWM hindcast, is archived at the Marine Environmental Data Service in Ottawa, Canada.

(ii) U.S. Army Waterways Experiment Station (WES) Spectral Hindcast

Twenty years (1956-1975) of historical wave data have been hindcast using the WES hindcast model (Corson et al, (9), Corson et al, (10) and Corson and Resio (11)). This hindcast used the same pressure data as the U.S. Navy hindcast, except that an improved definition of severe storms was used. Wave spectra were hindcast at a grid spacing of approximately 80km at 60 degrees north latitude, in deepwater locations along the east coasts of the United States and Canada, however, the data have been archived for only a limited number of grid points close to the edge of the continental shelf.

The wave data developed during the WES hindcast study is archived in Canada by the Marine Environmental Data Service (Ottawa). The data consist of directional wave spectra as well as parameters such as the characteristic wave height and peak period.

(iii) Department of Public Works - Parametric Hindcast Model

A wind-wave hindcast study was undertaken by Public Works Canada to define the wave climate at four locations in the Gulf of St. Lawrence and two locations in Lake Superior. Sixteen years of hourly values of significant wave height and peak period were hindcast at each location in the Gulf of St. Lawrence. Fifteen years of hourly wave statistics were hindcast at the two locations in Lake Superior. This hindcast was completed for the Transportation Development Centre, Montreal, as part of the Gulf Corridor Study (1).

A description of the hindcast study and a summary of the wave data

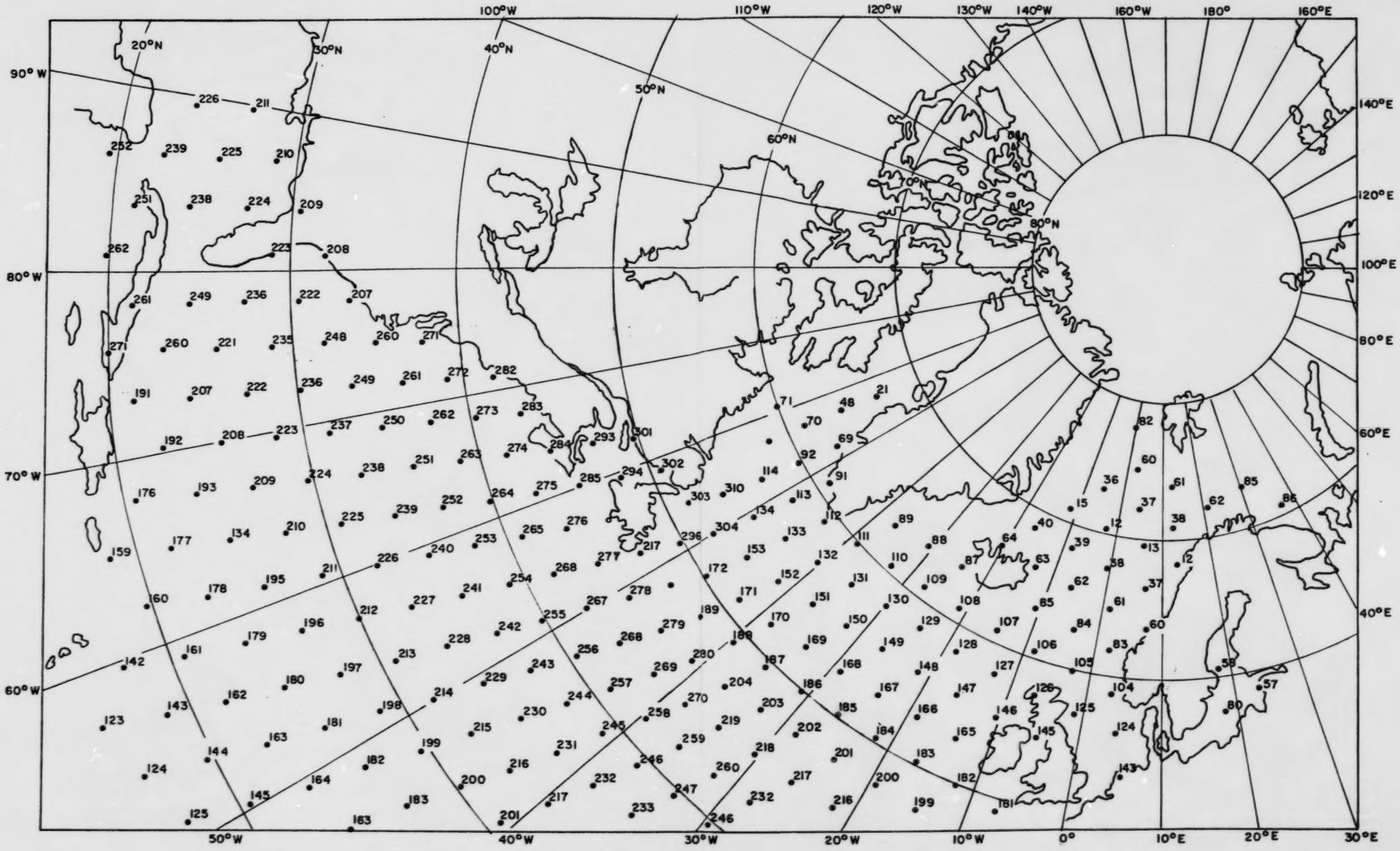


FIGURE 3.5 - U.S. NAVY SPECTRAL OCEAN WAVE MODEL (SOWM) GRID - NORTHWEST ATLANTIC

is provided in Baird (12).

(iv) U.S. Army Waterways Experiment Station - Great Lakes Wave Hindcast Study.

A numerical hindcast procedure was developed by the Waterways Experiment Station to provide reliable long-term design wave information for the Great Lakes by Resio and Vincent, (13). The model was used to calculate hourly values of two-dimensional wave spectra during major storms that occurred over the Great Lakes during the period between 1908 and 1976. The storm wave data were used to predict the 5, 10, 20, 50 and 100 year extreme return period events.

The extreme value significant wave heights and associated significant wave periods are published in a series of reports (Resio and Vincent (13)). Hourly values of two-dimensional spectra are stored on magnetic tape at the Waterways Experiment Station, Vicksburg, Mississippi.

(v) Beaufort Sea

Several hindcast studies have been undertaken on behalf of a number of oil companies involved in Arctic oil and gas exploration. These studies were designed to provide reliable estimates of the wave climate of the Beaufort Sea (Institute of Storm Research (14), Intersea Research Corporation (15), Atmospheric Environment Service (16), Dames and Moore (17), Berry et al (18) and Baird and Hall (19)).

Baird and Hall (19) hindcast 10 years (1970-1979) of hourly wave statistics for 6 locations in the southern Beaufort Sea using a parametric wind-wave hindcast model driven by historical surface wind data. At the present time, this Beaufort Sea wave hindcast data is proprietory.

(vi) General

A number of other wind-wave hindcast models have been developed in the past 20 years, and are listed in Bibliography 2. However, many of these hindcasts were for site-specific purposes, produced data that have not been archived in a readily retrieval form, are of questionable reliability, have not been used to produce long-term wave data or have primarily been used for experimental or verification uses. It is not possible within the terms of references of this study, to review all of these data, nor is it considered necessary to do so, as these data will have very limited application to future studies of ship response to waves.

3.5 Remote Sensing

Recent advancements in the past decade in remote sensing techniques, have made it possible to measure ocean waves over a large area from a

single source. The majority of effort has involved adapting existing technology to specific sensing requirements. Remote sensing techniques have been tested on board towers, ships, aircraft and more recently, satellites. Increases in the rate of sensing (speed of coverage, repeatibility) and the size of the area studied, have evolved because of improvements in the sensor systems and quality of the observations. However, Burkhart (20) notes that the development of ocean sensing techniques lags behind the development of meteorological and land resource sensing. Burkhart states that although considerable effort has gone into remote ocean-wave sensing in the past 25 to 30 years, the majority of existing wave data results from visual shipboard observations.

Remote ocean-wave sensing has utilized several techniques, including measurement of wave spectra using AM-CW radar on an ocean tower, a pulsed-sonic system, infra-red systems, laser systems, high-frequency radar and surface-reflectivity analysis (Ross (21)). Burkhart (20), provides a brief description of the most promising remote-sensing techniques for large-scale, high-speed sensing of the ocean surface. These are described briefly below:

1) Methods for Use in Satellites

Synthetic Aperature Radar (SAR)

The SAR has been designed to provide all-weather ocean-wave directional spectra, in addition to imagery of other oceanographic parameters. "The synthetic aperature radar produces a relatively incomprehensible signal phase history containing the return signal, its range and doppler location. This phase history is processed in an optical or digital processor where signal content is converted into grey-scale patterns from which wave patterns can be detected by shortening the dynamic range." Detection of the wave length patterns (of wave lengths greater than 25m) should permit detection of wave direction.

Radar Altimeter

A satellite radar altimeter sensor was used to measure ocean-wave heights from both SKYLAB and the GEOS-3 satellite. The purpose of the GEOS-3 mission, was to demonstrate that radar-altimetry data, when suitably processed, are capable of yielding sea-state measurements. Results of the GEOS-3 experiment are very satisfactory (Parsons (22), Parsons and Hayne, (23), Gower, (24)). Various authorities have estimated that with suitable calibration adjustments, the satellite measurements are accurate to +0.5m.

More recently, SEASAT A satellite has been instrumented with a more accurate radar altimeter and it is anticipated that the analysis and comparison of the data with ground truth data, will determine that the resolution of the system will be approximately 0.25m.

Pierson and Salfi (25) have used data recorded by the GEOS-3

satellite to verify wave data produced by the U.S. Navy Spectral Ocean Wave Model.

Microwave Radar Scatterometer

Active microwave scattering provides all-weather continuous measurements of sea-surface roughness from which surface winds can be estimated. The procedure was developed initially by Cox and Monk (26) who utilized photographs of the sun's glitter to estimate the sea-surface roughness. The drawback of the photographic method, is that it is restricted to fair-weather periods. Considerable study has been undertaken to understand sea scattering.

The development of all-weather microwave-scattering techniques, has most recently involved instrumentation of SKYLAB and comparison of the estimated wind speeds with ground-truth measurements. Several shortcomings were identified and have subsequently been corrected. A newly designed system was installed for trials in SEASAT A, and it is anticipated that estimated wind speeds between 4 and 26m/s will have a speed accuracy of 2m/s, with a directional accuracy of 20 degrees.

Microwave Radiometry

This system is used to estimate wind-speed based on measurement of sea-surface foam brightness. Previous experience includes deployment of a radiometer in both the SEASAT A and NIMBUS G satellites. Global coverage was provided every 72 hours by covering a 600km path on each orbit. Windspeed predictions of an order of 0 to 50m/s have an estimated accuracy of +2m/s.

Note: In 1978, SEASAT A was launched to assist in developing and demonstrating a global-ocean dynamics-monitoring system. However, after less than 100 days of operation, SEASAT failed. The satellite was equipped with:

i) radar altimeter to measure wave height (expected accuracy (H=0.5-25m 0.5m))

ii) synthetic operature radar to measure wave length (L=25-1000m 10m) and wave direction

iii) microwave scatterometer to measure wind speed (4-26m/s 2m/s and wind direction (0-360 degrees 20 degrees))

iv) microwave radiometer to measure wind speed (0-50m/s 2m/s)

Efforts are being made to continue the development of a concept similar to SEASAT which can be utilized to provide directional ocean wave spectra data, for both the north and south hemisphere, and assist in the study of many processes still not well understood, such as the development of freak waves.

2) Ground and Low-Altitude Systems

Waverider-Analyzer Satellite Communicator (WRANSAC)

This method employs the use of a waverider buoy to measure waves and transmitting data via satellite to a central collection agency, thereby providing real-time wave data. This method has been utilized sucessfully at several locations recently. The data is useful in preparing wave forecasts issued to mariners and can be used to provide early warning of major storms to the offshore drilling industry.

Surface Contour Radar (SCR)

This system is installed aboard an aircraft and is capable of measuring and obtaining directional sea-state information. The radar provides direct measurement of the surface elevation and relative intensity of backscatter from which directional data and wave-length resolution, is derived.

Over the Horizon Radar (OTH)

The accuracy of OTH radar measurement of wave climatology has been described as: .75m in wave height, 22 degrees in wave direction and 10 per cent in wave length. The system is currently being developed to provide information for the near-coastal zone (0-500mm offshore).

Many additional references dealing with remote sensing exist. Some of these are found in Bibliography 1F.

Much of the data recorded using remote-sensing techniques, is still being subjected to rigorous analysis including ground truth verification/calibration, accuracy estimation and repeatibility analyses, therefore at present, most of the wave data recorded during various test projects will not provide information useful to this present study.

4 WIND DATA

4.1 General

Wind data are classified into the following three categories, based on the source of data:

i) instrument measured winds, both overland and overwater

ii) observations of wind by observers on ships

iii) windfield data derived from sea-level pressure data

This section describes the wind data that are available through the archives of data collection services and provides references to data measured and retained by private companies and organizations.

The suitability and reliability of the wind data largely depends on:

(i) The continuity of data, both spatially and in time. In order to utilize the wind data for statistical purposes or for wave prediction, the wind data must be representative of a defined area over a long period of time. For wave prediction purposes, the time history, or sequence of observations, must be retained.

ii) Accuracy and reliability of the data. Much of the data were recorded using a variety of instrumentation and observation methods, which results in variable accuracy often within a particular data set.

iii) Consistency of the data. Many wind data files are assembled using data recorded at several stations in close proximity. However, the definition of surface wind is often subject to considerable variation. Many anemometers are not located at the same elevation, therefore it is extremely important to subject the wind data to a rigorous screening process in which the height of the anemometer is analyzed and all data is reduced to the prescribed level for defining surface wind.

Wind data sets developed for use in open ocean wind-wave hindcast programs should be re-constructed from direct analyses of measured or predicted sea-level pressure data. This is because the spacing and accuracy of ship-wind observations is often insufficient to properly describe the wind field directly, whereas pressures are relatively coherent over an area large enough to delineate major weather features (Overland, (27)).

4.2 Instrument Measurements

This section describes wind data that were measured directly using a variety of anemometer types. The data is reported under the organization responsible for archiving the data.

(i) Atmospheric Environment Service - Environment Canada

A listing of the AES holdings is presented in the AES Climatological Station Data Catalogues. The series contains six volumes based on geographically delineated areas. Overland wind speed and direction have been recorded at a number of coastal locations using the U2A or 45B anemometers.

(ii) Environmental Data Information Service (EDIS)

TDF-14 - Data File summarizes land station surface observations of wind speed and direction (also sea level pressure and temperature). There are only a few stations located on the coast of the United States, therefore, this data file does not provide many data representative of overwater wind conditions.

(iii) National Data Buoy Office, National Oceanic and Atmospheric Administration

The National Data Buoy Office has archived all available wind statistics recorded simultaneously with wave height using weather buoys at various locations in the coastal water of the United States. Most of the data is only measured for intermittent periods of time, therefore, the continuity and coverage of data in time and space is only moderate.

(iv) East Coast Rig Instrumentation Program (ECRIP)

As discussed in 3.3, the ECRIP was initiated by a group of companies involved in oil and gas exploration in the area of the Baltimore Canyon. The program is designed to collect wind, wave and temperature data at numerous exploration sites. However, at present, the data holdings are very limited.

(v) Private Holdings

Overwater wind data have been measured and analyzed for a number of offshore sites in the Great Lakes, Beaufort Sea and along the east coast of Canada. These data have been measured primarily at locations of oil and gas exploration activity and are very discontinuous both spatially and in time. The majority of these data are kept in private holdings by the organization responsible for recording them and are not archived by any data service agency.

4.3 Ship Observations

(i) Shipboard Synoptic Meteorological Observations

This data file is derived from shipboard observations of wind speed and direction. The data is summarized by date for each square on the main grid which covers the northern hemisphere. Each square is representative of an area one degree latitude by

one degree longitude. The format of the data is similar to the wave data summaries described in Section 3.3.

(ii) Environmental Data Information Service (EDIS)

TDF-11 - This data file represents a summary of meteorological and oceanographic data (wind speed and direction, surface atmospheric pressure and air and sea temperatures) collected by a number of sources including shipboard observations, ship weather reports, ship logs, observing buoys and from foreign meteorological agencies. The data is stored on magnetic tape by geographical area, each area being representative of a square grid, one degree of latitude by one degree of longitude. The data tapes are available from the National Oceanographic Data Centre.

4.4 Wind Data Derived From Pressure Field Data

A description of the marine wind field can be developed from the physical relationship between pressure fields and surface wind fields. Two complete sets of wind field data covering a period greater than 20 years were developed from pressure data in order to provide input to two different wind-wave hindcast models. Details of the wind field data are described below.

(i) Fleet Numerical Weather Central

A complete set of wind field data was developed for the northern hemisphere to provide input to FNWC'S Spectral Ocean Wave Model (SOWM). The wind data were derived from sea-level pressure data collected from many sources and blended together into an integrated file by Meteorology International Incorporated (MII). The pressure data file consists of four observations per day for each grid point on a 63 by 63 grid of the northern hemisphere (381km grid spacing at 60 degrees north latitude). Figure 4.1 shows the MII grid.

The wind data file is archived on magnetic tape at the Atmospheric Environment Service, Downsview, Ontario.

(ii) U.S. Army Waterways Experiment Station

Two sources of sea level pressure data were used to generate a pressure field for wave hindcasting purposes. The pressure field was constructed in order to re-construct 20 years of wind data over the Atlantic Ocean, Pacific Ocean and the Gulf of Mexico. The procedure for developing the wind file is described in Corson et al (9). Sea level pressure data discretized on a 381km grid supplied by Meteorology International Incorporated (MII) was integrated with Environmental Data Information Service (EDIS) tape deck TDF-11, which provided sea-level pressure data and air/sea temperature data for grid areas on a one degree latitude by one degree longitude grid of the northern hemisphere.

The NII grid was refined by WES because it was felt that the 381km grid was too coarse to accurately define interior portions of severe storms that are common at high latitudes. The procedure for subdividing the grid and blending the sea level pressure files is described in Corson et al (9).

The result of this procedure was the development of a 20 year (1956-1975) wind field representative of the historical wind field over the Atlantic Ocean. The data is discretized onto a 125 x 141 grid (approximately 95km at 60 degrees north latitude).

The WES wind field data, part of the Wave Information Study, is archived on magnetic tape by the Atmospheric Environment Service, Downsview Ontario.

5 WAVE PREDICTION METHODS

5.1 General Discussion

The sea state or the magnitude of the waves, on any body of water, can be predicted if the wind field over the water and its time history is known. The calculation requires a numerical model that should simulate the physical processes of wave generation by wind, wave growth, wave-wave interaction, wave propagation and wave-current interaction. If the physical processes are well represented by the numerical model, the reliability or accuracy of the prediction of the wave conditions is dependent on the accuracy of the description of the wind field over the generating area.

There are two categories of models. The simplest models represent an empirical approach that provides an estimate of the significant wave height and period, or similar parameters, and do not deal in depth with the physics of the problem. The other category includes the spectral models that describe the sea state by a directional variance spectrum. These models may include equations that deal with the spectral energy balance or the transfer of energy to different wave periods, and wind-wave interaction.

These latter models generally involve far more complex procedures than parametric models, and require extensive data processing capabilities to use the models.

In the simplest models, the wind velocity is assumed to be constant over the generating area, while in the complex models, the wind velocity is input at grid points over the generating area.

The accuracy of the latter model is partially dependent on the size of the grid and time interval between the wind velocity data. The wind data for the grid is determined from pressure gradients, although in some instances, these may be blended with ship observations of wind velocity. A more complete discussion of the state of the art of methods for sea state prediction are contained in Cardone and Ross (28).

Most wind-wave hindcasts, which are based on historical wind data, have been undertaken for specific sites and are of little use to a study that requires data representative of shipping routes. The exceptions to this are hindcasts completed by the U.S. Navy, the U.S. Army Corps of Engineers and a Government-Industry group concerned with oil and gas recovery in the North Sea.

The U.S. Navy Fleet Numerical Weather Central, undertakes continuous wave forecasts, using a spectral model, of the oceans of the world. Of particular interest to this study, is a 20-year hindcast of the North Atlantic, completed with the U.S. Navy Spectral Ocean Wave Model (SOWM). These data have been archived and are readily available.

The U.S. Army Corps of Engineers, have also completed a 20-year hindcast for the North Atlantic, using much the same pressure data as used in the U.S. Navy hindcast, but with an improved description of storms. This hindcast used a wave prediction model developed by Resio. The results of this hindcast have been archived for a number of grid points close to the edge of the U.S. and Canadian Continental Shelf.

Both of the above hindcasts do not, because of their grid size, include an accurate definition of the shoreline, nor do they include allowance for any shallow water effects. Consequently, they do not provide a reliable definition of the wave climate of coastal regions. The above models are discussed in detail in the following sections.

The North Sea hindcast provides data for the design of structures and operations associated with the recovery of oil and gas in the North Sea, and is not discussed in this report.

All of the above hindcasts required considerable effort in the development and editing of the wind data. They also required very extensive data processing capabilities to undertake the analyses.

While the U.S. Navy and U.S. Army Corps of Engineers hindcasts provide extensive coverage of the North Atlantic and the Labrador Sea, they do not provide similar coverage of the Canadian Arctic, Gulf of St. Lawrence, Great Lakes and Pacific Ocean. The U.S. Navy model is used to provide forecasts for the Pacific and there are plans for the U.S. Corps of Engineers to undertake a similar hindcast, as completed for the North Atlantic, in the Pacific Ocean.

Many hindcasts have been completed for the Great Lakes and Gulf of St. Lawrence and some hindcasts have been undertaken for Lancaster Sound and the Beaufort Sea. The major hindcasts are discussed in the following sections. For the most part, the hindcasts for the smaller enclosed bodies of water involved the simpler significant wave height models.

All hindcasts require wind velocity data and for many studies, these wind data are archived for each grid point for the period of the hindcast.

5.2 U.S. Navy Fleet Numerical Weather Central - Spectral Ocean Wave Model (SOWM)

Development of the SOWM hindcast procedure is discussed in Lazanoff and Stevens (8), and Lazanoff and Stevens (29). In addition to providing 48 hour wave forecasting capabilities, the model has been used to provide 20 continuous years of wave data for the northern hemisphere. The hindcast technique is based on theories of ocean wave energy propagation, dissipation and generation using wind fields derived from gridded sea level pressure data as input. The hindcast provides a description of the sea state on a 381km grid (approximately 3400 grid points in the northern hemisphere) which includes a description of directional wave spectra (defined by distribution over 15 frequencies

and 12 directions), wind velocity and wind direction at six hour intervals.

The pressure data used to derive the historical wind field, were assembled from a variety of sources including ship observation, ocean weather station data, ship-borne instrument measurements, etc. The pressure data was derived on a 63 by 63 grid of the northern hemisphere (approximately a 381km grid at 60 degrees north latitude). The pressure data and its consequential wind field, are discussed in 4.2.

The model takes into account the propagation of swell waves. If at the time of the calculation, the locally generated significant wave height at a particular grid point exceeds five feet, swell is propagated in a radial manner until the significant wave height of that train has decreased below three feet. The sea state at any grid point is described by the summation of the locally generated wave spectra plus the incoming swell from all directions.

There are numerous papers dealing with the verification of the SOWM model (Chen et al (30), Hoffman and Chen (31), Lazanoff and Steven (29), Hoffman and Burke (32) and Lazanoff (33)). Chen et al (30) reports that "In addition to the verification of the physics of wave energy growth, dissipation and propagation phenomena carried out by SOWM developers, extensive statistical results on the comparison of hindcast and measured spectra performed so far, further confirms SOWM's ability in hindcasting the long-term spectral properties and wave statistics at many areas of interest." Although the evaluations were limited to only a few selected locations where measured data were available, the results of the statistical analysis demonstrated that the SOWM consistently hindcast the wave properties in good agreement with the measured waves and, consequently, establishes the confidences in utilizing that data source for other geographical locations.

Hoffman and Chen (31) assess the applicability of using the SOWM hindcast directional wave spectra for calculating ship response and conclude without reservation, that FNWC spectra provide an accurate and effective model of describing sea conditions for use in calculating ship responses. Their study showed that the mean bending moment responses to hindcast measured wave spectra were in good agreement for all the ships evaluated, regardless of their size and geometrical form.

More research effort should be applied to the verification of the SOWM hindcast spectra. In particular, the effect of the large grid spacing should be evaluated. Hayes et al (34) found that the SOWM grid spacing was too coarse to effectively simulate the rapidly developing low pressure systems off the east coast of Labrador.

The David Taylor Naval Ship Research and Development Centre, has analyzed the SOWM hindcast wave spectra and have developed an environmental climatology described by distributions of wind speed, wind direction, wave height and wave period, predominant and secondary wave directions and spectral width (Bales and Cummins (35)). In addition, the Naval Weather Service Detachment has prepared frequency of occurrence and persistence statistics of various parameter

magnitudes calculated using the SOWM hindcast.

5.3 U.S. Army Engineers Waterways Experiment Station-Resio Model

A spectral hindcasting procedure was developed as part of the Wave Information Study (WIS) for the U.S. Coastlines. Development of the hindcast procedure, input data files and data presentation format, is described in a series of reports published by the WES (Corson et al (9), Corson et al (10), Resio (36) and Corson and Resio (11).

Development of the historical wind field data from several pressure data sources, is described in Corson et al (9) and is also briefly summarized in 4.4. The development of the hindcasting procedure involving wave energy propagation, dissipation and generation is described in Corson et al (10). The hindcast produces a directional wave spectral climatology at six-hour intervals on a grided system. At present, 20 years of wave data have been hindcast for grid locations along the U.S. Coastline and east coast of Canada. The grid spacing is approximately 95km at 60 degrees north latitude.

Extensive verification of the WES hindcast is still being undertaken. Preliminary results of the hindcast verification are provided in Corson and Resio (11) and Resio (30). Resio (37) assessed the validity of the WES hindcast wave data in the Scotian shelf, Grand Banks and Labrador Sea and concluded that problems could be encountered due to inadequate pressure information due to a grid that was too coarse.

Based on a comparison of available recorded and hindcast wave data for the Grand Banks and Scotian shelf areas, Baird and Readshaw (33) concluded that the WES hindcast data does not provide an adequate description of the wave climate in these areas.

5.4 Beaufort Sea Hindcast Model

A significant wave height model was used to hindcast ten years of hourly values of significant wave height and peak period at six locations in the Beaufort Sea. The work was undertaken for Gulf Canada Resources Canada Inc., and the results of the hindcast are proprietary.

A description of the overwater wind field was obtained by modifying overland wind data recorded at a coastal location on the Beaufort Sea. The modification was based on a transformation function developed by comparing simultaneous records of winds recorded over the Beaufort Sea and winds recorded at Tuktoyaktuk. The transformation function was applied to the overland wind frequency statistics to provide correct simulation of the overwater wind frequency statistics. A detailed description of the wind modification procedure is described in Baird and Hall (19).

The hindcast procedure also included a moving ice fetch. Fetch lengths limited by the position of the ice peak were calculated using weekly summaries of Beaufort Sea ice conditions.

The wave hindcasting procedure was verified using comparisons of all available recorded data. Approximately 45 months of wave data recorded at 15 locations, was compared to hindcast wave data for corresponding periods of time.

6 SHIP RESPONSE ANALYSIS AND WAVE DATA REQUIREMENTS

A ship must be designed to successfully withstand large structural forces and dynamic movements imposed on the system by the ships response to major environmental loadings, including wind, wave, ice and current loadings which act interactively and individually. Under most circumstances, wave loading provides the major influence on the response of marine vessels and structures.

The design and evaluation of ships to ensure structural integrity and tolerable dynamic response, requires a reliable description of the sea-state climatology for the intended area of operation and a complete description of the response characteristics of the ship. The response characteristics of the ship (response amplitude operators) can be determined using theoretical analyses or hydraulic model tests. However, proper definition of the sea state for each particular area of consideration will require a considerable amount of development and interpretation. Current ship design practices utilize a probablistic approach, therefore, various statistical parameters such as the probability of encountering various sea states, long-term variation in spectral shape, joint distribution of wave height and wave period, directionality of the energy density spectra and the anticipated ship speed, heading and exposure time, must be considered.

In addition to the definition of ship bending stresses and wave impact loading, it is necessary to analyze both transient and steady state hull vibrations resulting from dynamic impact loading being applied to the ship due to bottom slamming, bow flare impact and shipping green water. It has been shown that whipping stresses (resulting from transient wave-induced hull vibration) can be in the same order of magnitude as wave bending stresses. These stresses may cause serious structural damage to ships, in particular, panel buckling (McCallum, (39), Resio (40) and Yamamoto et al, (41)). Maximum whipping stresses occur in a ship travelling in rough seas. The significance of springing stresses (steady-state wave-induced hull vibrations) is still not clear, however, it is apparent that high frequency springing stresses will increase the cumulative fatigue damage to the hull.

At present, ship response is predicted by using an idealized spectral formulation to represent a variety of spectral shapes which may describe a particular sea state defined by a particular wave height and wave period parameter. Several reliable spectral formulations exist and have been used to predict ship response. Results of a study (Ochi and Bales (42)) undertaken to compare the vessel response predicted using several spectral formulations for a number of vessel types, are presented below.

The spectral formulations most widely used (generally the Bretschneider two parameter spectra) are single-peaked spectra. Some concerns have arisen because many spectra representative of moderate to high seas, are double-peaked. A ship's response to a secondary peak near the natural frequency of a particular ship response may be a much larger response than that caused by the primary peak. One example is the roll

response of a ship which tends to increase during encounters with long period swells. A six-parameters double-peaked spectral formulation, was developed by Ochi and Hubble (43) and was based on extensive analyses of several hundred measured ocean spectra.

Ochi and Bales (42) computed the response of ships, including pitch, roll, vertical acceleration and wave-induced forces and movements, to a variety of spectral formulations which included the Bretschneider, Pierson-Moskowitz, JONSWAP, Darbyshire, Voznesenski-Netsevatayer and the six-parameter spectral formulations. The response of five types of vessels, of varying size and configuration, was computed for each of the spectral formulations and was compared to the responses calculated using measured ocean-wave spectra. It was found that the response values calculated using spectral formulations fell within the range of responses calculated using the measured spectra. There was a large variability in spectral shape for a given range of significant wave heights. The study did not conclude that any one particular type of spectra was more successful in predicting the dynamic and structural response of a vessel to wave interaction because of the variation in measured spectra, however, it has been well-documented that ship response is dependent upon spectral shape.

Because the magnitude of a ship's responses varies considerably with the shape of the spectra, it is important to examine and define the limit of application of standard spectral formulations, because it is certain that marine vehicles will encounter an infinite variety of wave spectra types for any given sea-state level (categorized by a certain significant wave height). In addition, the question of directionality of the wave spectra must be examined. None of the presently used spectral formulations described the magnitude of the frequency components by direction. The use of directional spectra is still the subject of much research, and will be discussed later in this report.

The prediction of the long-term response of ships is an important consideration in ship design and evaluation. In order to predict the long-term response characteristics of a ship, it is important to accurately represent long-term wave statistics and to account for the variability in spectral shape, for a given sea state.

An established procedure has been used to calculate long-term wave induced ship response in different sea states, by using spectral formulas developed from measured wave spectra and calculated simplistic spectral formulations. However, the method was developed primarily to deal with a limited description of the sea state. A vast increase in the number of available wave spectra has occurred with the development of the U.S. Navy's SOWM hindcast (see 3.4, 5.2). This has resulted in the development of an alternate approach to calculating long-term wave-induced ship response (Chen and Hoffman (43)). A brief description of both methods follows, and summarizes the work of Chen et al (30):

i) Calculate the response amplitude operators for the vessel for a variety of ship speeds and headings. This is accomplished using theoretical derivations or hydraulic model tests

ii) Define the characteristics of the specific wave groups by using either directional spectra or single-point spectra, transformed using the cosine- squared spreading function.

iii) When undertaking long-term prediction of wave-induced ship responses, it is important to take into account the variability of wave energy spectral shape, because the wave conditions cannot be assumed to be stationary as they are when analyzing short-term trends. Ship response will differ greatly with variations in spectral shape for a given wave height. The procedure currently used assumes a normal distribution of rms response values around the mean value, thereby taking into account spectral variability.

iv) A spectral "family" for each wave height group is randomly selected out of the available spectra. Group properties, represented by significant wave height, period and energy, scattered at each frequency, are used to define the spectral family.

v) The response of the vessel to the spectral families is calculated.

However, with the development of an increased data set using hindcast spectra (SOWM results), a new method replacing step (iv) was developed, because the vessel response is sensitive to not only the mean rms value, but to the standard deviation (which is influenced directly by sample size). The new method developed by Chen and Hoffman (44), estimates the unbiased mean and variance of the rms response through superposition of the response amplitude operators with the mean-covariance spectra which is derived from a statistical analysis of the spectral ordinates (by frequency) in each wave height group.

The probability of exceeding a specified threshold can be determined from this data.

The final stage in calculating long-term wave-induced ship response, is to assess the probability of exceeding threshold values during a specified period of operation.

It can be seen from the above analysis, that a complete, accurate description of the sea state must include sufficient spectral information, long-term wave statistics, an understanding of the variability of spectral shape for a given wave height group (often categorized by significant wave height) and knowledge of the distribution of wave heights (or wave height groups), by determining exceedance and persistence statistics.

One question that still remains the topic of debate, is whether or not calculations using directional spectra provide a more accurate assessment of ship response than calculations using single-point spectra transformed using the cosine-spreading function. Studies are required to evaluate the effect of the dominant wave direction and to examine the effect of varying location on long-term trends

in the spectral climatology. Hoffman and Chen (44) discuss the response of ships to directional spectra. A comparison was made of responses (including pitch, roll, vertical acceleration and mid-ship bending moment) calculated using the conventional method, which is superimposing the response operators for a specific ship, onto the eight-point spectra family for one wave height group, using the cosine-squared spreading function with the responses calculated using hindcast direction spectra. Ship responses were averaged over all spectra and over all ship headings. The results indicate that the spreading method (whether the cosine-squared spreading function, or computed or measured directional spectra were used), does not significantly affect the results of the analysis with the exception of a ship in beam-sea conditions. Since the severity of the sea state shows a definite relationship to direction of maximum wave energy, it was concluded that the use of the cosine-squared spreading function may bias the distribution of ship responses defined by ship heading, because the cosine-squared spreading function tends to underestimate the variability in the directional distribution of the wave energy spectra.

The wave data developed for use in the prediction of wave-induced ship response must also provide information on the joint distribution of wave height and wave period for two reasons. First, the likelihood of significant wave height-period combinations in the area of interest should be determined. In addition, many of the theoretical spectral formulations used to predict long-term wave-induced ship response (if no measured data exist) require the estimation, or derivation of certain parameters and weighting factors, to generate the idealized spectra.

7 SUMMARY AND DISCUSSION

7.1 Wave Data

The following discussion summarizes the major characteristics of the available wave data and comments on their value to future studies of ship strength.

(i) Instrument Wave Data

- only intermittent and short-term coverage available

- do not contain information of wave direction (for the most part)

- essential for the validation of wind-wave prediction methods and for defining wave conditions during research programs

(ii) Ship Observations

- do not provide a sufficiently reliable or detailed description of the sea state

- statistical summaries are valuable for preliminary comparisons of wave climates of different areas

- not suitable for in-depth analyses of ship strength

(iii) Hindcast Wave Data

- most suitable form of wave data for studies of ship strength, provided discrete spectral models are used for predictions in the oceans

- wave prediction models must be verified by comparing with recorded wave data

- wave prediction models can provide many years of reliable wave data consistantly over all areas of interest. The data can include directional wave spectra.

(iv) Remote Sensing

- remote sensing may provide useful data in the near future, for the verification of wave prediction models, in particular, for verification of directional spectra

- remote sensing may provide the most complete, reliable description of global real-time wave conditions, for use in real-time and prognastic wave forecasts to aid in ship routing

It is considered that a Canadian capability to predict wave conditions over the oceans using winds developed from surface pressure charts,

must be developed. The prediction model should be of the discrete spectral type, capable of producing an accurate description of the directional wave spectrum. The predictions must be fully proven by comparing with recorded wave data.

The Marine Environmental Data Service, of Fisheries and Oceans Canada, also has an interest in developing a wave prediction capability and discussion should be had with them concerning a joint development program.

For the immediate requirement of defining the wave climate of the eastern seaboard of Canada and the United States, hindcast wave data that cover 20 years and were produced by the U.S. Navy SOWM model and the U.S. Army Corps of Engineers Resio model should be considered. The first step should be to substantiate the data by systematically comparing them with wave spectra recorded in Canadian and U.S. waters and carefully reviewing results of other comparisons that have been undertaken using recorded wave data.

The discrete, spectral hindcast models will produce directional multi-peaked spectra that are required for analysis of ship response. The SOWM results have been extensively used in recent years to calculate low and high frequency response of many types of ships to environment of the North Atlantic.

However, these hindcast models do not provide a complete description of the sea state. In particular, unique wave events that may cause excessive slamming and whipping stresses, cannot be predicted. To the north east of Cape Hatteras, an area on the proposed Caribbean route, "freak waves" have been encountered that were produced by north-easterly waves interacting with the northerly flowing Gulf Stream. These conditions are reported to have caused the loss of the tanker Texaco Oklahoma in 1971 and the Bulk Carriers Anita and Norse Variant in 1971 and 1973. These "freak waves" cannot be defined by available prediction methods.

7.1.1 Ship Stress Calculations and Requirements for Wave Data

In order to adequately assess all aspects of the dynamic behaviour and structural response of a ship to waves, the following characteristics of describing the overall wave climatology of the area under consideration, must be defined:

i) Long-term wave statistics must be developed, including an understanding of long-term variations in spectral shape, probability levels of various sea states, joint distribution of wave height and wave period, frequency of occurrence of wave height and wave period, etc.

ii) Directional spectral climatology

iii) Understanding of wave steepness, wave grouping and the occurrence of "freak" waves in the study area

In addition, it is equally important to estimate as accurately as possible, the anticipated ship speed, ship heading and exposure time for each ship route considered.

Further investigation must be undertaken to determine the response of ships to directional spectra.

8 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn and recommendations are made with respect to the long-term objective of developing Canadian technology for assessing ship strength requirements and developing and applying regulations that ensure the safety of Canadian shipping:

1. Reliable and consistent wave data suitable for ship strength calculations and representative of shipping routes off the east coast of Canada and the United States, the Canadian Arctic and other routes used by Canadian ships, can only be obtained using wind-wave prediction procedures. The wind-wave prediction procedure must be able to adapt to the unique physical characteristics of each area where wave data are required (for example, procedures for Canadian Arctic may be different from those suitable for the east coast of Canada).

2. Procedures for predicting wave conditions should exist in Canada and should include the definition of over-water wind fields, the use of a discrete spectral model and the production of wave data in a format suitable for the many different users. The development and/or purchase of suitable procedures will be a major undertaking that should be supported by Government Departments other than Transport Canada. The availability of a Canadian procedure will be a major benefit to Fisheries and Oceans Canada, Public Works Canada, Canadian Oil and Gas Lands Administration, the Armed Forces (METOC centre), as well as private industry, in particular, the oil industry.

3. In the future, strength standards and regulations for ships and floating structures may be based on the calculation of the actual stress distribution in a ships structure resulting from interaction with a defined wave climate representative of the proposed route. Transport Canada should gain experience in the use of numerical procedures for calculating ship response to the directional wave spectra that will be provided by the wave prediction procedures. The procedures should include linear and non-linear dynamic stress analysis methods. A methodology for determining ship response to wave steepness and other parameters not directly defined by the wave prediction procedure, should be developed.

4. The assessment of the results of strength calculations produced by a defined wave climate and the development of standards and regulations is complex and involves discussion concerning acceptable levels of probability of failure. Assessment procedures must also consider the probability of extreme events being encountered by the ship, errors in design, errors in construction, faulty material and the methodology used for the design of the ship or floating structure. Transport Canada should develop and substantiate procedures to be used for Canadian regulations.

5. For the immediate consideration of the proposed route to Kingston, Jamaica, the approval of this route by the new vessels should be based on calculation of ship stresses produced in the vessel by defined sea states. The wave climate data required for these analyses should be defined using the results of the SOWM or WES 20-year wave hindcast.

6. The role of specific studies of individual ships instrumented to measure stress in the ships structure, should be carefully reviewed. Studies that involve a dedicated program of trials using an extensively instrumented ship and complete monitoring of the wave conditions incident on the ship will be essential in developing improved capabilities in ship design. However, field studies of limited scope may produce data that will have little use in the overall development plan, or in assessing the strength of the ship. It is recommended that field studies be part of carefully designed long-range studies.

Specific recommendations concerning the development of a Canadian capability for predicting the wave conditions on the oceans over long periods of time are as follows:

(i) An in-depth, state-of-the-art report on discrete wave hindcast models should be prepared as a first step in developing a Canadian capability in wave prediction. This report would have the objective of recommending either the purchase of an existing model or the development of a new model. This report may also include the results of items (ii) and (iii) below.

(ii) The results of the SOWM prediction model should be verified by comparing the results with available recorded wave data. This verification should include comparison of recorded and hindcast storm profiles defined by the signficant wave height and peak period, and a comparison of recorded and hindcast variance spectra.

(iii) The results of the revised WES wave prediction model should be verified for Canadian waters by comparing the results with available recorded wave data. The revised WES model was provided by Dr. Resio to MEDS in the spring of 1982, and includes as grid adjusted to suit the Canadian shoreline.

(iv) Research should be undertaken to derive statistically or artificially, using actual wave records for calibration and verifications, a description of wave characteristics unique to particular areas of interest including a description of wave steepness, and wave groupiness.

With regard to the development of procedures for calculating ship response to waves, the following recommendation is made:

- An in-depth, state-of-the-art report should be prepared on methodologies for calculating ship response. This report will pay particular attention to the problem of dynamic loadings. The report

should include a summary of existing expertise available around the world and a summary of programs that are available for purchase.

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APPENDIX A-1

SUMMARY OF MEDS HISTORICAL WAVE MEASURING STATIONS

CANADIAN MARINE DATA INVENTORY REPORT

D. HISTORICAL WAVE MEASURING STATIONS

REFERENCE C81043D01

IDENTIFICATION		LOCATION			DATES		INSTRUMENT		
ID.	NAME	IHB ZONE	LATITUDE DD-MM-SS	LONGITUDE DDD-MM-SS	DEPTH METRES	START DD/MM/YY	STOP DD/MM/YY	SUCCESS TYPE	ANALYSIS	
002	GUYANA	1850	07-24-28N	058-18-00W	N/A	22/02/74	19/03/74	WR	G	S
003	TUKTOYAKTUK	2800	69-53-48N	135-57-12W	21	26/08/74	30/08/74	WR	A	S
003	"	2800	69-53-48N	135-57-12W	21	08/08/75	06/09/75	WR	A	S
004	VICTORIA HARBOUR	3600	48-25-25N	123-23-16W	5	10/03/76	24/03/77	WR	G	S
008	PORT AUX BASQUES	2000	47-33-00N	059-06-00W	44	05/12/74	07/02/75	WR	A	S
009	GRAND BAY (INNER)	2000	47-34-36N	059-12-36W	14	05/10/74	17/12/74	WR	G	S
010	GRAND BAY (OUTER)	2000	47-35-00N	059-17-40W	91	27/04/74	17/12/74	WR	G	S
015	M V TYPHOON	2100	54-17-00N	055-07-00W	30	21/07/71	02/09/71	WR	G	S
016	LOGY BAY	2100	47-38-18N	052-28-18W	168	31/07/72	14/12/72	WR	G	S
016	LOGY BAY	2100	47-38-12N	052-27-48W	168	22/06/73	20/01/74	WR	G	S
016	"	2100	47-38-12N	052-27-48W	168	25/06/74	22/01/75	WR	G	S
016	"	2100	47-38-12N	052-27-48W	168	06/06/75	13/01/76	WR	G	S
016	"	2100	47-36-06N	052-26-40W	167	17/06/76	31/01/77	WR	G	S
016	LOGY BAY	2100	47-36-06N	052-26-40W	167	08/06/77	09/01/78	WR	G	S
016	"	2100	47-37-00N	052-25-27W	166	16/06/79	13/02/80	WR	A	S
016	LOGY BAY	2100	47-37-00N	052-25-27W	166	18/05/80	31/12/80	WR	G	S
016	"	2100	54-17-46N	055-07-20W	165	31/07/73	29/08/73	WR	G	S
017	PELICAN (LEIF M-48)	2100	55-30-00N	057-42-00W	139	31/08/73	25/10/73	WR	G	S
017	PELICAN (BJARNI H-81)	2100	54-54-00N	055-52-00W	300	19/08/74	01/09/74	WR	G	S
017	PELICAN (GUDRID H-55)	2100	55-30-44N	057-45-00W	139	30/09/74	17/10/74	WR	G	S
017	PELICAN (BJARNI H-81)	2100	53-56-13N	054-42-35W	188	05/07/75	05/08/75	WR	G	S
017	PELICAN (FREYDIS B-87)	2100	58-52-00N	061-46-00W	180	11/08/75	23/09/75	WR	G	S
017	PELICAN (KARLSEFNI A-13)	2100	54-39-00N	055-40-00W	310	27/09/75	29/10/75	WR	G	S
017	PELICAN (CARTIER D-70)	2100	57-20-00N	059-58-00W	141	29/08/76	07/09/76	WR	G	S
017	PELICAN (SNORRI J-90)	2100	58-52-00N	061-47-00W	180	13/09/76	23/10/76	WR	G	S
017	PELICAN (KARLSEFNI A-13)	2100	55-30-00N	058-14-00W	137	27/07/79	25/08/79	WR	A	S
017	PELICAN (TYRK P-100)	2100	58-52-06N	062-06-20W	183	14/09/79	08/10/79	WR	G	S
017	PELICAN (GILBERT F-53)	2100	58-52-06N	062-06-20W	198	18/07/80	11/09/80	WR	G	S
017	PELICAN (GILBERT F-53)	2100	57-19-45N	059-57-44W	141	01/08/75	09/10/75	WR	G	S
018	SEDCO 445	2100	47-01-48N	053-37-18W	55	31/03/74	22/01/75	WR	A	S
019	ADMIRALS BEACH	2000	48-29-24N	058-42-00W	28	07/10/74	29/10/74	WR	G	S
020	STEPHENVILLE	2000	48-29-24N	058-42-00W	28	06/12/74	19/01/75	WR	G	S
020	"	2000	48-29-24N	058-42-00W	28	30/05/75	26/11/75	WR	G	S
020	"	2100	47-32-36N	052-39-30W	53	08/04/76	27/04/76	WR	G	S
021	DEADMANS BAY	2100	47-31-33N	052-37-57W	59	08/04/76	27/04/76	WR	G	S
022	CAPE SPEAR	2100	59-50-00N	061-45-00W	N/A	01/08/76	28/08/76	WR	A	S
023	PETREL	2100	52-26-05N	054-12-00W	N/A	03/09/76	22/09/76	WR	G	S
023	PETREL	2100	55-31-47N	057-42-34W	144	30/07/79	20/10/79	WR	G	S
023	PETREL	2100	55-31-00N	057-45-00W	N/A	30/08/76	20/11/76	WR	G	S
024	ZAPATA UGLAND	2800	69-58-05N	134-59-00W	15	08/08/76	09/10/76	WR	A	S
025	PULLEN ISLAND	1860	45-49-40N	060-03-40W	33	28/04/76	12/01/77	WR	G	S
026	GABARUS BAY	2000	45-17-25N	064-09-05W	18	30/06/75	01/12/75	WR	G	S
027	MINAS BASIN	2000	45-17-25N	064-09-05W	18	13/04/76	23/11/76	WR	A	S
027	"	1860	45-49-36N	060-04-48W	24	28/05/75	12/02/76	WR	A	S
028	GABARUS BAY	1860	45-49-36N	060-04-48W	24	29/04/76	13/01/77	WR	A	S
028	"									

CANADIAN MARINE DATA INVENTORY REPORT

D. HISTORICAL WAVE MEASURING STATIONS

REFERENCE C81043D01

IDENTIFICATION		LOCATION			DATES		INSTRUMENT		
ID.	NAME	IHB ZONE	LATITUDE DD-MM-SS	LONGITUDE DDD-MM-SS	DEPTH METRES	START DD/MM/YY	STOP DD/MM/YY	SUCCESS TYPE	ANALYSIS	
029	POINT LEPREAU	1860	44-57-00N	066-27-00W	91	21/05/75	01/06/76	WR	A	S
031	WESTERN HEAD	1860	44-00-42N	064-36-12W	40	27/04/70	04/07/71	WR	A	S
031	WESTERN HEAD	1860	44-00-49N	064-36-10W	43	03/09/71	04/05/72	WR	G	S
031	"	1860	44-00-49N	064-36-10W	43	18/08/72	05/05/73	WR	G	S
032	CAPE ROSEWAY	1860	43-31-18N	065-12-06W	37	11/06/70	29/10/70	WR	G	S
032	"	1860	43-31-18N	065-12-06W	37	08/12/70	04/06/72	WR	G	S
036	GLACE BAY	1860	46-13-30N	059-26-15W	46	02/12/70	11/01/71	WR	A	S
036	GLACE BAY	1860	46-08-00N	059-30-00W	46	23/04/71	04/10/71	WR	A	S
037	OSBORNE HEAD	1860	44-32-40N	063-27-50W	30	12/12/70	29/12/70	WR	G	S
037	"	1860	44-32-40N	063-27-50W	30	06/03/71	15/02/73	WR	A	S
037	OSBORNE HEAD	1860	44-32-49N	063-27-32W	30	27/02/73	28/01/75	WR	A	S
037	"	1860	44-32-49N	063-27-32W	30	03/03/75	01/09/76	WR	A	S
037	OSBORNE HEAD	1860	44-29-25N	063-24-15W	57	01/09/76	31/12/80	WR	A	S
040	TINER POINT	1900	45-08-54N	066-11-42W	31	14/02/72	22/09/72	WR	A	S
040	TINER POINT	1900	45-09-15N	066-10-46W	31	24/09/72	22/03/73	WR	G	S
040	TINER POINT	1900	45-08-33N	066-12-23W	14	26/01/77	22/05/78	WR	G	S
042	CAPE TORMENTINE	1860	46-08-13N	063-46-23W	7	12/06/73	20/11/73	PC	G	S
043	MAGDALEN (OUTER)	2000	47-36-06N	061-18-04W	27	23/05/74	17/12/74	WR	A	S
043	"	2000	47-36-06N	061-18-04W	27	26/06/75	14/12/75	WR	G	S
043	"	2000	47-36-06N	061-18-04W	27	28/06/76	19/11/76	WR	G	S
043	"	2000	47-36-06N	061-18-04W	27	02/07/77	21/07/77	WR	G	S
043	MAGDALEN (OUTER)	2000	47-37-18N	061-18-18W	15	14/07/78	08/12/78	WR	A	S
044	MISCOU ISLAND	2000	48-10-30N	064-16-00W	46	30/05/74	21/11/74	WR	A	S
045	FOX RIVER A	2000	49-00-19N	064-23-00W	8	15/05/74	10/07/74	WR	G	S
045	FOX RIVER A	2000	49-00-18N	064-23-17W	18	15/05/75	10/11/75	WR	G	S
045	FOX RIVER A	2000	49-00-19N	064-23-00W	9	19/07/78	05/12/78	WR	A	S
046	FOX RIVER B	2000	48-59-08N	064-23-00W	5	24/05/74	18/09/74	PC	A	S
047	FOX RIVER C	2000	48-59-47N	064-23-17W	3	15/05/75	10/11/75	WR	G	S
048	MAGDALEN (INNER)	2000	47-38-01N	061-31-10W	13	28/06/76	19/11/76	WR	G	S
048	MAGDALEN (INNER)	2000	47-38-12N	061-31-02W	13	02/07/77	29/11/77	WR	G	S
048	MAGDALEN (INNER)	2000	47-38-06N	061-31-00W	13	16/07/78	07/12/78	WR	A	S
050	PULLEN ISLAND	2800	69-57-05N	133-50-05W	15	08/08/76	08/10/76	WR	A	S
051	SEPT ILES	2000	50-11-53N	066-23-03W	8	12/06/72	08/12/72	PC	A	S
052	STE ANNE DES MONTS	2000	49-09-15N	066-30-00W	61	07/07/71	29/11/71	WR	G	S
052	"	2000	49-09-15N	066-30-00W	61	09/06/72	22/11/72	WR	A	S
053	RIMOUSKI	2000	48-31-15N	068-28-25W	7	13/08/71	24/11/71	ST	A	S
054	MATANE	2000	48-50-31N	067-34-45W	7	26/07/72	23/10/72	ST	P	S
056	TINER POINT	2000	45-09-12N	066-12-12W	8	21/04/77	12/06/78	ST	G	S
057	LES ESCOUMINS	2000	48-12-06N	069-18-55W	91	29/04/74	30/09/74	WR	A	S
057	LES ESCOUMINS	2000	48-13-39N	069-16-18W	91	01/10/74	07/11/74	WR	G	S
058	CAPUCINS	2000	49-04-41N	066-48-54W	36	20/06/75	11/11/75	WR	G	S
059	CAPE TORMENTINE	2000	46-10-00N	063-45-00W	17	09/07/76	17/11/76	WR	G	S
060	MAIN DUCK ISLAND	2950	43-47-45N	076-49-39W	69	19/04/72	21/11/72	WR	A	S
062	KINCARDINE (OUTER)	2950	44-10-48N	081-38-48W	6	20/10/73	18/12/73	PC	G	S
063	KINCARDINE (INNER)	2950	44-10-36N	081-38-24W	3	07/10/73	18/12/73	PC	G	S

IDENTIFICATION		LOCATION			DATES		INSTRUMENT		
ID.	NAME	IHB ZONE	LATITUDE DD-MM-SS	LONGITUDE DDD-MM-SS	DEPTH METRES	START DD/MM/YY	STOP DD/MM/YY	SUCCESS TYPE	ANALYSIS	
064	COBOURG	2950	43-49-05N	078-02-05W	69	12/04/72	04/12/72	WR	A	S
064	COBOURG	2950	43-53-15N	078-09-12W	69	29/03/73	12/12/73	WR	G	S
065	TORONTO	2950	43-30-23N	079-19-42W	108	11/03/72	15/04/73	WR	A	S
066	POINT PELEE S	2950	41-55-16N	082-15-24W	18	03/04/72	30/06/72	WR	A	S
066	"	2950	41-55-16N	082-15-24W	18	02/09/72	13/11/72	WR	P	S
066	"	2950	41-55-16N	082-15-24W	18	31/03/73	29/12/73	WR	A	S
067	GODERICH (INNER)	2950	43-44-42N	081-43-21W	7	14/08/72	07/12/72	PC	A	S
068	GODERICH (OUTER)	2950	43-44-46N	081-43-49W	7	14/08/72	07/12/72	PC	A	S
069	GODERICH (WB)	2950	43-44-49N	081-44-27W	8	02/09/72	07/12/72	WR	G	S
070	GRAND BEACH	2960	50-38-55N	096-38-30W	9	22/06/71	10/11/71	WR	G	S
070	"	2960	50-38-55N	096-38-30W	9	18/05/72	23/10/72	WR	A	S
070	"	2960	50-38-55N	096-38-30W	9	22/05/73	05/06/73	WR	A	S
071	GIMLI	2960	50-38-55N	096-54-00W	9	15/09/71	07/11/71	WR	G	S
071	"	2960	50-38-55N	096-54-00W	9	10/06/72	23/10/72	WR	G	S
072	COVE ISLAND	2950	45-19-24N	081-56-18W	65	26/05/73	17/11/73	WR	G	S
073	BATTLE ISLAND	2950	48-41-24N	087-33-06W	219	16/05/73	17/11/73	WR	A	S
074	KINGSTON	2950	44-06-20N	076-34-58W	30	25/07/73	30/11/73	WR	A	S
074	KINGSTON	2950	44-06-03N	076-35-04W	29	27/06/75	08/08/75	WR	G	S
074	"	2950	44-06-03N	076-35-04W	29	09/06/76	08/09/76	WR	G	S
075	POINT PELEE W	2950	41-57-00N	082-35-00W	12	22/05/74	06/01/75	WR	A	S
076	POINT PELEE E	2950	41-57-00N	082-24-00W	16	10/05/74	11/12/74	WR	G	S
077	BURLINGTON (INNER)	2950	43-17-18N	079-43-06W	26	04/06/76	16/06/76	WR	P	S
077	BURLINGTON (INNER)	2950	43-16-12N	079-45-24W	13	22/09/76	28/09/76	WR	P	S
077	BURLINGTON (INNER)	2950	43-16-48N	079-44-18W	14	27/04/77	23/11/77	WR	G	S
077	BURLINGTON (INNER)	2950	43-16-08N	079-44-03W	14	27/09/78	30/11/78	WR	G	S
079	WHEATLEY (B)	2950	42-02-00N	082-27-00W	13	11/04/79	26/12/79	WR	G	S
079	"	2950	42-02-00N	082-27-00W	13	17/04/80	17/12/80	WR	G	S
080	EDDY POINT	1860	45-31-06N	061-14-05W	46	31/05/72	15/02/73	WR	G	S
081	WHEATLEY (K)	2950	42-03-39N	082-27-47W	6	15/04/79	04/01/80	ST	G	S
081	"	2950	42-03-39N	082-27-47W	6	18/04/80	19/12/80	ST	G	S
082	BURLINGTON (CCIW)	2950	43-20-32N	079-46-16W	N/A	31/10/72	16/12/72	WR	P	S
082	"	2950	43-20-32N	079-46-16W	N/A	22/08/73	18/09/73	WR	P	S
082	"	2950	43-20-32N	079-46-16W	N/A	15/11/73	15/12/73	WR	P	S
083	PARKER POINT	1860	45-21-21N	061-19-40W	37	30/11/73	16/01/74	WR	G	S
083	"	1860	45-21-21N	061-19-40W	37	06/06/74	10/12/74	WR	A	S
084	CHEDABUCTO BAY	1860	45-28-24N	061-10-30W	27	25/10/74	11/02/75	WR	G	S
084	"	1860	45-28-24N	061-10-30W	27	04/05/75	04/02/76	WR	G	S
085	MELFORD POINT	1860	45-32-15N	061-17-43W	29	10/12/74	08/02/75	WR	P	S
085	"	1860	45-32-15N	061-17-43W	29	11/04/75	04/02/76	WR	A	S
086	BARROW STRAIT	2500	74-37-00N	092-20-00W	N/A	16/08/76	20/08/76	WR	G	S
088	PRINCE RUPERT	2900	54-14-12N	130-20-17W	27	19/04/76	23/07/76	WR	G	S
089	HAY RIVER	2960	60-57-24N	115-42-45W	18	18/06/75	30/09/75	WR	A	S
090	SEDCO J (FLYING FOAM I-13)	1850	47-02-42N	048-46-31W	91	12/10/73	26/11/73	WR	G	S
090	SEDCO J (BONNITION H-32)	1851	45-51-27N	048-19-32W	108	08/12/73	30/12/73	WR	G	S
090	SEDCO J (CITNALTA I-59)	1860	44-08-42N	059-37-30W	59	25/02/74	19/04/74	WR	G	S

CANADIAN MARINE DATA INVENTORY REPORT

D. HISTORICAL WAVE MEASURING STATIONS

REFERENCE C81043D01

IDENTIFICATION		LOCATION			DATES		INSTRUMENT		
ID.	NAME	IHB ZONE	LATITUDE DD-MM-SS	LONGITUDE DDD-MM-SS	DEPTH METRES	START DD/MM/YY	STOP DD/MM/YY	SUCCESS TYPE	ANALYSIS	
090	SEDCO J (INTREPID L-80)	1860	43-49-37N	059-56-44W	37	14/06/74	11/08/74	WR	G	S
090	SEDCO J (ADOLPHUS D-50)	1851	46-59-05N	048-22-29W	113	26/10/74	31/10/74	WR	G	S
090	SEDCO J (ADVENTURE F-80)	1860	45-19 30N	057-56-30W	99	22/01/75	0 /02/75	WR	G	S
090	SEDCO J (CUMBERLAND B-55)	1800	48-24-12N	050-07-58W	N/A	08/08/75	13/10/75	WR	G	S
090	SEDCO J (INDIAN HARBOR M-52)	2100	54-22-00N	054-24-00W	N/A	27/09/76	12/10/76	WR	G	S
091	SEDCO H	2000	47-11-10N	061-11-10W	61	13/06/73	03/09/73	WR	G	S
091	SEDCO H	2000	47-58-33N	063-07-06W	58	12/09/73	22/11/73	WR	G	S
091	SEDCO H	1851	45-15-03N	054-23-14W	120	06/12/73	22/01/74	WR	G	S
091	SEDCO H	1860	43-46-15N	061-46-13W	79	04/02/74	27/02/74	WR	G	S
091	SEDCO H	1860	43-41-25N	060-46-12W	92	04/03/74	19/05/74	WR	G	S
091	SEDCO H	1851	43-38-17N	062-48-15W	92	27/05/74	27/06/74	WR	G	S
091	SEDCO H	1860	45-29-19N	058-32-18W	110	04/07/74	30/07/74	WR	G	S
091	SEDCO H	1860	46-34-45N	059-45-00W	100	16/08/74	28/09/74	WR	A	S
091	SEDCO H	1860	44-41-41N	057-52-33W	46	16/06/76	22/09/76	WR	P	S
091	SEDCO H	1860	43-34-26N	060-25-45W	N/A	01/10/76	15/11/76	WR	P	S
091	SEDCO H	1860	43-04-55N	062-16-43W	110	14/01/77	11/02/77	WR	G	S
091	SEDCO H	1860	44-10-02N	060-06-32W	61	24/02/77	29/03/77	WR	G	S
092	SEDNETH	1851	44-43-29N	049-27-23W	59	27/07/73	30/08/73	WR	A	S
093	SEDCO I	1851	46-25-38N	048-50-22W	86	16/08/73	10/09/73	WR	A	S
093	SEDCO I	1851	45-49-06N	049-04-06W	N/A	13/09/73	14/10/73	WR	A	S
093	SEDCO I	1851	44-16-59N	052-42-19W	86	02/12/73	10/12/73	WR	G	S
093	SEDCO I	1851	45-45-41N	052-08-32W	86	20/02/74	21/02/74	WR	G	S
093	SEDCO I	1851	45-23-32N	052-35-02W	86	28/04/74	04/07/74	WR	P	S
093	SEDCO I	1851	45-20-27N	048-52-26W	85	10/09/74	29/09/74	WR	G	S
094	HAVDRILL	2100	49-08-06N	051-14-27W	335	09/07/74	03/10/74	WR	G	S
094	HAVDRILL	2100	49-08-00N	051-14-00W	335	11/06/75	11/08/75	WR	A	S
094	HAVDRILL	2100	54-21-51N	054-23-49W	196	17/08/75	21/10/75	WR	G	S
095	VICTORIA (K)	2900	48-25-41N	123-23-27W	4	03/12/75	12/04/76	ST	G	S
095	"	2900	48-25-41N	123-23-27W	4	09/07/76	28/07/76	ST	A	S
097	HALIBUT BANK	2900	49-20-36N	123-44-06W	53	11/01/74	16/05/74	WR	A	S
098	HERSCHEL ISLAND	2800	69-00-00N	139-00-00W	N/A	01/08/70	30/08/70	WR	P	S
100	OWS PAPA	3600	50-00-00N	145-00-00W	4000	02/02/74	11/02/74	PC	P	S
100	"	3600	50-00-00N	145-00-00W	4000	13/01/75	12/09/76	PC	A	S
100	"	3600	50-00-00N	145-00-00W	4000	01/11/76	07/04/80	PC	G	S
100	"	3600	50-00-00N	145-00-00W	4000	02/07/80	31/12/80	PC	A	S
102	STURGEON BANK	2900	49-10-12N	123-18-46W	110	07/02/74	15/08/74	WR	A	S
102	"	2900	49-10-12N	123-18-46W	110	18/11/74	01/04/76	WR	A	S
103	TOFINO	2900	48-59-27N	125-44-39W	40	26/06/70	27/09/70	WR	P	S
103	"	2900	48-59-27N	125-44-39W	40	02/04/71	21/05/71	WR	A	S
103	"	2900	48-59-27N	125-44-39W	40	07/07/71	20/12/71	WR	A	S
103	"	2900	48-59-27N	125-44-39W	40	02/02/72	12/07/72	WR	P	S
103	"	2900	48-59-27N	125-44-39W	40	02/02/73	23/06/73	WR	A	S
103	"	2900	48-59-27N	125-44-39W	40	02/09/73	31/12/80	WR	A	S
104	PRINCE RUPERT	2900	54-11-09N	130-30-06W	91	28/09/72	13/06/73	WR	A	S
106	WEST VANCOUVER	2900	49-20-44N	123-13-45W	40	19/12/72	18/05/74	WR	G	S

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IDENTIFICATION		LOCATION				DATES		INSTRUMENT		
ID.	NAME	IHB ZONE	LATITUDE DD-MM-SS	LONGITUDE DDD-MM-SS	DEPTH METRES	START DD/MM/YY	STOP DD/MM/YY	SUCCESS TYPE	ANALYSIS	
108	ROBERTS BANK	2900	49-01-05N	123-16-07W	139	07/02/74	01/11/74	WR	P	S
108	"	2900	49-01-05N	123-16-07W	139	23/04/75	03/04/76	WR	G	S
108	ROBERTS BANK	2900	49-04-18N	123-22-48W	250	25/06/81	29/06/81	WR	G	S
111	POWELL RIVER (INNER)	2900	49-50-18N	124-31-50W	6	10/12/76	14/03/77	WR	G	S
112	POWELL RIVER (OUTER)	2900	49-50-18N	124-31-50W	9	10/12/76	14/03/77	WR	G	S
113	KINCOLITH	2900	54-59-51N	129-58-48W	37	06/10/77	26/02/78	WR	A	S
114	FRENCH CREEK (INNER)	2900	49-21-02N	124-21-15W	4	24/11/76	24/02/77	WR	G	S
115	FRENCH CREEK (OUTER)	2900	49-21-02N	124-21-15W	7	24/11/76	15/03/77	WR	A	S
116	WHITE ROCK	2900	49-00-30N	122-50-00W	13	24/10/77	03/03/78	WR	A	S
117	LUND	2900	49-58-52N	124-45-58W	37	12/10/77	25/03/78	WR	A	S
118	KITIMAT	2900	53-58-52N	128-39-12W	37	08/10/77	22/03/78	WR	A	S
121	GIBSONS LANDING	2900	49-24-00N	123-30-00W	37	30/03/78	03/04/79	WR	G	S
122	POINT GREY	2900	49-17-03N	123-16-22W	11	05/07/78	12/08/78	WR	G	S
122	POINT GREY	2900	49-16-42N	123-16-00W	5	22/08/78	30/07/79	WR	A	S
123	FISHERMANS COVE (WB)	2900	49-21-00N	123-42-00W	50	11/04/79	27/03/80	WR	G	S
124	FISHERMANS COVE (K)	2900	49-21-18N	123-16-28W	6	06/04/79	27/03/80	ST	A	S
127	BAY BULLS	2100	47-18-51N	052-48-39W	17	21/07/77	13/11/77	WR	A	S
127	"	2100	47-18-51N	052-48-39W	17	11/01/78	22/01/78	WR	P	S
129	HARBOUR GRACE	2100	47-40-39N	053-14-09W	10	24/07/78	16/02/79	WR	A	S
129	HARBOUR GRACE	2100	47-41-21N	053-12-44W	17	11/06/78	24/07/78	WR	G	S
131	DISCOVERER 7-SEAS	1800	49-37-34N	049-18-29W	1524	16/05/79	17/08/79	WR	A	S
132	SEDCO 707	2100	51-10-23N	051-04-30W	241	12/06/79	18/10/79	WR	G	S
133	SEDCO 709	1851	46-44-21N	048-49-00W	72	07/01/80	11/07/80	WR	A	S
134	SEDCO 706	1851	46-47-05N	048-45-26W	110	22/03/80	06/01/81	WR	G	S
134	SEDCO 706 (HEBRON I-13)	1851	46-32-48N	048-32-23W	94	29/01/81	25/05/81	WR	A	S
134	SEDCO 706 (HEBRON I-13)	1851	46-32-20N	048-31-35W	70	23/07/81	10/09/81	WR	G	S
134	SEDCO 706 (NAUTILUS C-92)	1851	46-51-21N	048-44-55W	90	22/10/81	13/02/82	WR	G	S
135	NEDRILL II	2100	54-51-37N	054-44-41W	273	06/07/80	03/09/80	WR	G	S
135	NEDRILL II	2100	55-31-35N	057-40-38W	156	16/09/80	17/10/80	WR	G	S
136	GLOMAR ATLANTIC	1851	46-46-20N	048-46-00W	82	01/06/79	21/10/79	WR	A	S
136	GLOMAR ATLANTIC	2100	55-48-50N	058-26-37W	490	31/07/80	25/09/80	WR	G	S
137	PELLERIN	2100	58-26-00N	061-46-00W	N/A	20/08/78	17/09/78	WR	G	S
137	PELLERIN	2100	55-00-00N	055-30-00W	269	16/07/79	01/10/79	WR	G	S
137	PELLERIN	2100	57-31-30N	060-26-36W	159	16/08/80	08/10/80	WR	G	S
138	BEN OCEAN LANCER	2200	62-11-08N	062-58-17W	360	22/07/79	10/08/79	WR	A	S
138	"	2200	62-11-08N	062-58-17W	360	25/07/80	05/10/80	WR	G	S
140	ZAPATA UGLAND (HIBERNIA P-15)	1851	46-46-20N	048-46-00W	82	25/11/79	07/01/80	WR	P	S
140	ZAPATA UGLAND	1851	46-34-36N	048-21-15W	98	31/01/80	30/08/80	WR	G	S
140	ZAPATA UGLAND	1851	47-07-55N	047-58-12W	150	30/09/80	02/04/81	WR	G	S
140	ZAPATA UGLAND (HIBERNIA K-18).	1851	46-48-23N	048-47-35W	70	26/06/81	03/11/81	WR	G	S
140	ZAPATA UGLAND (WEST FLYING FOA	1851	47-03-12N	048-44-48W	95	15/11/81	17/02/82	WR	G	S
141	BEN OCEAN LANCER	2100	55-52-00N	058-51-00W	562	18/08/78	28/09/78	WR	G	S
142	ROWAN JUNEAU	1860	44-02-00N	059-32-00W	24	21/09/80	16/12/80	WR	G	S
143	SAULNIERVILLE	1860	44-15-20N	066-10-00W	9	27/05/77	03/06/77	WR	G	S
143	SAULNIERVILLE	1860	44-15-50N	066-08-45W	7	03/06/77	11/11/77	WR	G	S

CANADIAN MARINE DATA INVENTORY REPORT

D. HISTORICAL WAVE MEASURING STATIONS

REFERENCE C81043D01

IDENTIFICATION		LOCATION			DATES		INSTRUMENT		
ID.	NAME	IHB ZONE	LATITUDE DD-MM-SS	LONGITUDE DDD-MM-SS	DEPTH METRES	START DD/MM/YY	STOP DD/MM/YY	SUCCESS TYPE	ANALYSIS	
143	SAULNIERVILLE	1860	44-15-20N	066-10-00W	9	12/11/77	22/03/79	WR	A	S
144	GULF TIDE	1800	43-44-00N	060-20-30W	60	09/03/78	06/11/78	WR	A	S
144	GULF TIDE	1800	43-47-45N	059-37-35W	60	06/11/78	10/06/79	WR	P	S
145	BEN OCEAN LANCER	1800	42-51-42N	061-55-21W	955	03/05/78	03/08/78	WR	G	S
146	CHIGNECTO BAY	1860	45-41-28N	064-32-59W	11	14/06/78	06/08/78	WR	G	S
146	CHIGNECTO BAY	1860	45-33-24N	064-49-18W	11	06/08/78	13/12/78	WR	G	S
147	CAPE ENRAGE	1860	45-44-54N	064-36-24W	37	14/06/78	19/02/79	WR	G	S
148	LUNENBERG (K)	1860	44-22-30N	064-18-30W	6	14/12/78	06/11/79	ST	A	S
149	LUNENBERG (WB)	1860	44-21-06N	064-17-36W	12	14/12/78	27/11/79	WR	G	S
150	EMERALD BASIN	1860	43-55-24N	062-38-12W	190	16/11/79	21/11/79	WR	G	S
151	ROLLS COVE	2100	47-34-00N	052-41-10W	N/A	20/09/80	31/12/80	WR	G	S
152	POINTE SAPIN	2000	46-59-42N	064-41-00W	20	05/06/79	04/12/79	WR	A	S
152	"	2000	46-59-42N	064-41-00W	20	07/05/80	12/08/80	WR	G	S
153	SALENERGY IV	2000	46-36-15N	061-37-30W	64	12/06/80	29/07/80	WR	G	S
153	SALENERGY IV	2000	46-39-20N	061-54-45W	56	01/08/80	26/08/80	WR	A	S
155	NEDRILL II-B	2100	54-52-30N	055-45-06W	285	22/08/80	08/09/80	WR	G	S
156	OCEAN RANGER	N/A	46-24-16N	048-53-10W	N/A	04/12/80	23/02/81	WR	G	S
156	OCEAN RANGER (HIBERNIA K-18).	1851	46-47-58N	048-47-58W	80	02/03/81	05/06/81	WR	G	S
156	OCEAN RANGER (SHERIDAN J-87).	1851	48-26-50N	049-57-58W	209	25/06/81	04/11/81	WR	G	S
156	OCEAN RANGER (HIBERNIA J-34).	1851	46-43-57N	048-50-43W	78	13/12/81	09/02/82	WR	G	S
161	ST FABIEN	2000	48-23-48N	068-57-39W	28	31/05/77	30/07/77	WR	A	S
162	FOX RIVER A(K)	2000	48-59-45N	064-23-03W	4	30/06/78	05/12/78	ST	P	S
163	FOX RIVER B(K)	2000	48-59-43N	064-23-11W	3	04/07/78	20/09/78	ST	A	S
174	PORT ELGIN (K)	2950	44-26-45N	081-24-50W	2	18/05/77	27/11/77	ST	G	S
175	PORT ELGIN (WB)	2950	44-27-00N	081-25-00W	11	18/05/77	29/11/77	WR	G	S
190	GULF I	2800	70-03-30N	133-38-00W	33	15/08/77	13/10/77	WR	G	S
191	GULF II	2800	70-08-24N	136-24-48W	43	16/08/77	10/10/77	WR	G	S
192	CANMAR I	2800	70-11-18N	132-45-12W	34	07/08/77	02/10/77	WR	G	S
192	CAN MAR I	2800	70-10-03N	132-44-00W	31	22/07/78	04/10/78	WR	P	S
193	CANMAR II	2800	70-23-54N	135-06-00W	64	07/08/77	01/10/77	WR	G	S
193	CANMAR II	2800	70-22-54N	135-05-36W	57	02/09/78	04/10/78	WR	G	S
194	ISSERK	2800	69-57-30N	134-26-00W	14	11/08/77	16/09/77	WR	P	S
196	EXPLORER III	2800	70-34-06N	130-51-24W	27	31/08/78	01/09/78	WR	G	S
196	EXPLORER III (KOAKOAK).	2800	70-28-00N	134-06-00W	60	07/08/81	06/10/81	WR	G	S
198	ISSUNGNAK	2800	70-04-00N	132-27-00W	24	04/08/78	13/08/78	WR	G	S
198	ISSUNGNAK	2800	70-03-20N	133-59-36W	24	19/08/79	15/10/79	WR	G	S
200	EXPLORER I	2800	70-31-07N	133-20-05W	46	03/08/79	10/09/79	WR	G	S
200	EXPLORER I	2800	70-05-00N	136-40-00W	N/A	11/08/80	18/09/80	WR	G	S
201	EXPLORER II (TARSUIT)	2800	69-58-08N	136-36-09W	30	13/08/79	18/09/79	WR	A	S
201	EXPLORER II	2800	70-34-00N	134-35-00W	N/A	16/08/80	13/09/80	WR	G	S
201	EXPLORER II (ISSUNGNAK).	2800	70-05-00N	134-26-00W	27	28/07/81	31/08/81	WR	G	S
202	EXPLORER IV	2800	70-49-00N	130-18-00W	N/A	15/08/80	07/09/80	WR	G	S
202	EXPLORER IV (KILANNAK).	2800	70-46-00N	129-21-00W	25	05/08/81	14/08/81	WR	G	S

APPENDIX A-2

SUMMARY OF THE NATIONAL DATA BUOY OFFICE WAVE RECORDING STATIONS IN NORTH AMERICAN WATERS

TABLE A.2

NDBO WAVE DATA
AS OF JUNE 1982

ACTIVE STATIONS

STATION/BUOY ID	DATES	WAVE SYSTEM	LOCATION
REGION 41000			
41004	05-80 - 02-81	WDA	32.6/78.7
	06-81 - 07-81	WDA	
	09-81 - 05-82	WDA	
	06-82	WDA	
41006	05-82 - 06-82	WDA	29.3/77.3
REGION 44000			
44003	04-79 - 07-79	WDA	40.8/68.5
	09-79 - 06-81	WDA	
	10-81 - 05-82	WDA	
	06-82	WDA	
44005	12-78 - 05-79	WSA	42.7/68.3
	06-79 - 05-80	WDA	
	12-80 - 01-81	WDA	
	03-81 - 05-82	WDA	
	06-82	WDA	
44006	10-80 - 03-81	DWDA	36.3/75.4
	07-81 - 03-82	DWDA	
44007	02-82 - 03-82	WDA	43.5/70.1
	04-82 - 05-82	WDA	
	06-82	WDA	
REGION 46000			
EB03	12-74 - 04-76	EEP	56.0/148.0
	07-76 - 01-78	WSA	
46001	02-78 - 10-78	WSA	
	02-79 - 09-79	WSA	
	10-79 - 04-81	WDA	
	06-81 - 05-82	WDA	
	06-82	WDA	
EB16	08-76 - 06-77	WSA	42.5/130.0
	08-77 - 01-78	WSA	
46002	02-78 - 04-79	WSA	
	05-79 - 05-82	WDA	
	06-82	WDA	

TABLE A.2 (Cont.)

NDBO WAVE DATA
AS OF JUNE 1982

ACTIVE STATIONS

REGION 46000

STATION/BUOY ID	DATES	WAVE SYSTEM	LOCATION
EB17	07-76 - 01-78	WSA	52.0/156.0
46003	02-78 - 07-78	WSA	
	11-79 - 01-80	WDA	
	12-80 - 11-81	WDA	
	02-82 - 05-82	WDA	
	06-82	WDA	
EB19	08-76 - 10-76	WSA	51.0/136.0
	12-76 - 05-77	WSA	
	07-77	WSA	
46004	09-78 - 05-80	WSA	
	02-81 - 01-82	WDA	
	03-82 - 05-82	WDA	
	06-82	WDA	
EB21	09-76 - 01-77	WSA	46.0/131.0
	11-77 - 01-78	WSA	
46005	02-78 - 05-80	WSA	
	06-80 - 05-82	WDA	
	06-82	WDA	
EB20	04-77 - 01-78	WSA	41.0/138.0
	02-78 - 12-79	WSA	
	05-81 - 05-82	WDA	
	06-82	WDA	

Table A.2 (Cont.)

NDBO WAVE DATA
AS OF JUNE 1982

INACTIVE STATIONS

STATION/BUOY ID	DATES	WAVE SYSTEM	LOCATION
EB13	06-75	EEP	32.3/75.2
	08-75	EEP	
EB41	10-75 - 11-75	WSA	38.7/73.6
	01-76 - 09-76	WSA	
	11-76 - 03-77	WSA	
	06-77 - 12-77		
41003	10-79 - 01-81	WDA	30.3/80.4
	03-81 - 01-82	WDA	
41005	05-80 - 09-80	WDA	31.7/79.7
	12-80 - 08-81	WDA	

APPENDIX A-3

PIANC GLOSSARY OF WAVE TERMS

EXTRACTED FROM

BULLETIN NUMBER 15, VOL. II, 1973
REPORT ON THE INTERNATIONAL COMMISSION
FOR THE STUDY OF WAVES
PERMANENT INTERNATIONAL ASSOCIATION OF
NAVIGATION CONGRESSES

APPENDIX No. 1

A SET OF TERMS, DEFINITIONS AND NOTATIONS FOR WIND GENERATED WATERWAVES AND THEIR ANALYSIS

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1. **Introduction.**

The Commission believes that the adoption of standardized notation will greatly facilitate the exchange of information pertaining to waves and recommends that wherever possible, the notation presented in the following glossary be used. The current usage must change and adapt to progress, and researchers and engineers are encouraged to adequately define, with reference to the methods used in calculations, the notations used.

2. **Definition of general terminology and dimensions.**

The " mean water level " is the average water surface over a period of at least one year.

The " still water level " is the level of the water surface in the absence of wave activity.

The " mean record level " is the average water surface over the period of observation (for instance 20 min.).

(The definition of mean record level, which is of importance in the zero-crossing type of analysis, is not concise when significant variation in water surface elevation is caused by the tide within the duration of the record. Floating buoys tend to filter out this long period movement whereas staff gauges do not.)

A " wave record " is an analogical or digital recording of wave parameters over a *stated continuous interval*. In particular, a wave record may be an analogical or digital recording of the water surface elevation or pressure resulting from the passage of waves.

A " zero-crossing " is to be understood as the crossing of the mean record level by the water surface at that instant (after filtering tide effects).

A crest or maxima is an event where the water surface has zero slope, is preceded by a positive slope and followed by a negative slope.

A trough or minima is an event where the water surface has zero slope, is preceded by a negative slope and followed by a positive slope.

The subscript Z should be used to indicate zero-crossing waves.

The subscript 0 should be used to indicate deep water waves.

The subscript *b* should be used to indicate breaking waves.

The subscript *c* should be used to indicate crests or maxima.

The subscript *t* should be used to indicate troughs or minima.

The subscript *v* should be used to indicate visual observations.

The subscript max should be used for referring to the maximum value of the variable.

The overbar $\bar{}$ denotes an average value of the variable. (The use of the overbar $\bar{}$ to denote an average value may not be acceptable in some countries and the use of brackets $< >$ or the subscript mean may be more acceptable.)

a This symbol should be used when referring to wave amplitude measured with respect to the mean record level.

H This symbol should be used when referring to wave height.

T This symbol should be used for referring to an interval of time related to the periodic property of waves.

L This symbol should be used for referring to wave length.

α This symbol to be used for the direction of wave propagation. It is the angle between true north and the direction from which the waves are coming. Clockwise direction is positive.

Z This symbol to be used for the vertical distance from an average value of the water surface to the bottom.

All variables and measurements should be dimensioned according to the S.I. system. In particular :

— space variable such as wave height, depth, etc., are given in meters ;

— frequency as applied to gravity waves should be given in Hertz (Hz).

3. Parameters defined directly from a wave record.

Z_1 The " mean water depth " is the vertical distance between the mean water level and the bottom. Z_1 is always a positive quantity.

Z_2 The " still water depth " is the vertical distance between the still water level and the bottom. Z_2 is always a positive quantity.

Z_3 The " mean record water depth " is the vertical distance between the mean record level and the bottom. Z_3 is always a positive quantity.

η_i The vertical distance of the instantaneous water surface to the mean record level, positive is used for the upward direction.

a_c The crest amplitude is the vertical distance between the mean record level and a crest or maxima.

$a_{z,c}$ The zero-crossing crest amplitude is the maximum vertical distance between the mean record level and the maximum level that occurred between an upward and a following downward going zero crossing. $a_{z,c}$ is always a positive quantity.

a_t The trough amplitude is the vertical distance between the mean record level and a trough or minima.

$a_{z,t}$ The zero-crossing trough amplitude is the maximum vertical distance between the mean record level and the minimum level that occurred between a downward and a following upward going zero-crossing. $a_{z,t}$ is always a positive quantity.

Y_1 The maximum wave level is the maximum zero-crossing crest amplitude observed in a record $= a_{z,c,max}$

Y_2 The minimum wave level is the maximum zero-crossing trough amplitude observed in a record. Note that Y_2 is always positive and is $= a_{z,t,max}$

H The " wave height " is the vertical distance between a crest and the immediately preceding trough.

H_z The zero up-crossing wave height is the sum of $a_{z,c}$ and the immediately preceding $a_{z,t}$. (Confusion may exist between the use of Hz for Hertz and H_z for the zero-crossing wave height.)

H_{max} The maximum wave height is the maximum H as observed in a specified period of time, which should always be stated.

$H_{z,max}$ The maximum zero up-crossing wave height is the maximum H_z as observed in a specified period of time, which should always be stated.

T_z The zero-crossing wave period is the interval of time between two adjacent downward going zero-crossings.

$T_{Hz,max}$ The period of the maximum zero up-crossing wave height is the interval between the preceding and the following downward going zero-crossings of a maximum zero up-crossing wave height.

4. Statistical parameters (1) derived from 3.

$H_{n\%}$ The wave height exceedance is the value of H exceeded by $n\%$ of all waves occurring in a specified period. For example $H_{1\%}$ (20 min.) is the wave height that is exceeded by only 1% of all waves occurring in a 20 min. period of observation. In particular one may use $H_{50\%}$ the median wave height. In some countries, the notation $H_{n\%}$ is used to denote the average of the highest $n\%$ of the waves in a record. Care should be exercised to properly interpret the intended meaning in individual publications.

$H_{z,n\%}$ The zero up-crossing wave height exceedance is the value of H_z that is exceeded by $n\%$ of all waves occurring in a specified period.

$\overline{H}_{1/n}$ The average of the highest $1/n^{th}$ of the H values for a stated period of time. In some countries, the notation $H_{1/n}$ is used to denote the wave height exceeded by $1/n^{th}$ of the waves. Care should be taken to properly interpret the intended meaning in individual publications.

$\overline{H}_{z,1/n}$ The average of the highest $1/n^{th}$ of the H_z values for a stated period of time. In particular one may use $\overline{H}_{z,1/3}$ (20 min.).

(1) $H_{n\%}$, $H_{z,n\%}$, $H_{1/n}$ and $H_{z,1/n}$ are tentative and not definitive proposals of the Commission.

$\bar{T}_z$ The zero-crossing wave period is the average of zero-crossing intervals as obtained by dividing the record duration by the number of times the water elevation crosses the mean record level in one direction.

$\bar{T}_c$ The average crest period is the time obtained by dividing the record duration by the total number of crests in this record.

ε_T The spectral width parameter (Broadness factor) defined by $\varepsilon_T^2 = 1 - (\bar{T}_c/\bar{T}_z)^2$.

$p(x)$ The probability density function of a wave parameter x, such as height or period.

$P(x)$ The distribution function of a wave parameter x and is known as $P(x) = \int_{-\infty}^{x} p(\lambda).d\lambda$.

5. Parameters derived from the variance spectrum analysis.

f_p The peak frequency is the frequency at which the maximum variance spectral density occurs.

T_p The peak period $= 1/f_p$.

$S(f)$ The variance spectral density function of a wave record is the density distribution of the variance η as a function of frequency.

$S(f,\alpha)$ The directional variance spectral density of a wave record is the density distribution of the variance η as a function of frequency and direction.

m_n The n^{th} moment of the variance spectral density function. $m_n = \int_a^b f^n S(f)df$. Typically $a = 0$ $b = \infty$.

σ The root mean square value is the square root of the variance or the average squared displacement of the water surface from the mean record level $\sigma^2 = \overline{\eta^2} = m_0$.

H_{m_0} The characteristic wave height $= 4^*\sigma$ for a stated period of time.

$T_{m_{a,b}}$ The length of time defined by two spectral moments m_a and m_b. In particular, on may use the " average period " defined as m_0/m_1 or m_{-1}/m_0.

ε_0 The spectral width parameter defined by

$$\varepsilon_0^2 = \frac{m_0 . m_4 - m_2^2}{m_0 . m_4}$$

6. Parameters derived from visual observations.

H_v The wave height as estimated from visual observation.

T_v The wave period as obtained visually.

7. Significant wave height.

The current use of this term, significant wave height, is confusing. There appear to be 3 common concepts of significant wave height :

a) the wave height parameter as computed from the RMS-value of the record ;

b) the average of the highest one third of the " wave heights " obtained autographically ; or

c) the visually estimated wave height following W.M.O. practices.

As noted in the above, the following three definitions are recommended :

H_{m_0} The characteristic wave height $= 4^*\sigma$ for a stated period of time.

$H_{1/3}$ (or H_s) The average of the highest one third of the zero up-crossing wave heights for a stated period of time.

H_v The wave height as estimated from visual observation.

APPENDIX A-4

LIST OF ORGANIZATIONS PRODUCING OR ARCHIVING WAVE DATA

LIST OF ORGANIZATIONS

Marine Environmental Data Service
Department of Fisheries and Oceans
240 Sparks St.
Ottawa, Ontario
(613) 993-2007

Atmospheric Environment Service
Environment Canada
4905 Dufferin St.
Downsview, Ontario
M3H 5T4
(416) 667-4953

National Oceanic and Atmospheric Administration
Environment Data and Information Service
National Climatic Centre
Federal Building
Asheville, North Carolina
USA, 28801
(704) 258-2850

National Oceanic Data Centre
Environmental Data Information Service
Ocean Services Branch
2001 Wisconsin Ave.
Washington, D.C.
USA, 20235
(202) 634-7500

National Data Buoy Office
Bay Saint Louis
Mississippi
USA
(601) 688-2806

National Oceanic and Atmospheric Administration
National Ocean Survey
6001 Executive Dr.
Rockville, Maryland
USA, 20852
(301) 443-8487

US Army Engineer
Waterways Experiment Station
PO Box 631
Vicksburg, Mississippi
USA, 39180
(601) 636-3111

LIST OF ORGANIZATIONS (Continued)

Environment Canada
Ocean and Aquatic Affairs
Atlantic Oceanographic Laboratory
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
B2Y 4A2
(902) 426-2431

Canadian Forces METOC Centre
CFH Halifax, Nova Scotia
Canada

US Navy
Fleet Numerical Weather Central
Monterey, California
USA

US Naval Weather Service Detachment
Asheville, North Carolina
USA, 28801

APPENDIX B

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1. Wind and Wave Data
2. Wind and Wave Forecasting (Hindcasting) Procedures
3. Wave Induced Ship Stresses and Ship Response

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